



Research Article

# An efficient method for the synthesis of 2,4,5-trisubstituted imidazoles using lactic acid as promoter



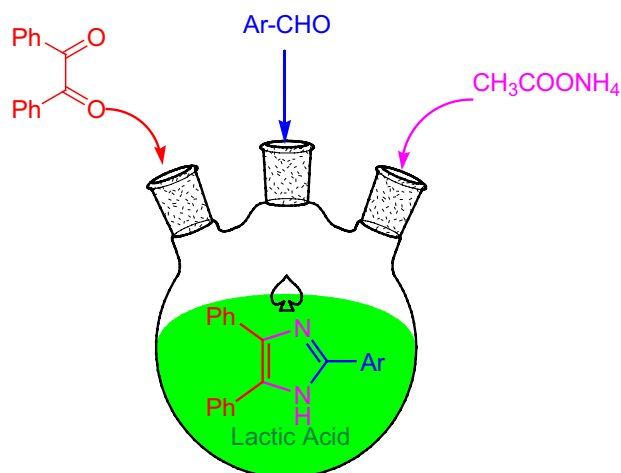
Jayant Sonar<sup>1</sup> · Sandeep Pardeshi<sup>1</sup> · Shrikant Dokhe<sup>1</sup> · Rajendra Pawar<sup>4</sup> · Kiran Kharat<sup>5</sup> · Ashok Zine<sup>2</sup> · Babasaheb Matsagar<sup>3</sup> · Kevin Wu<sup>3</sup> · Shivaji Thore<sup>4</sup>

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## Abstract

Synthesis of 2,4,5-trisubstituted imidazole compounds from an aromatic aldehyde, benzil and ammonium acetate is demonstrated using biodegradable lactic acid at 160 °C. This method is a simple, environmentally benign, and works for aromatic aldehyde containing electron donating and electron withdrawing groups.

## Graphic abstract



**Keywords** Lactic acid · Promotor · Green solvent · 2,4,5-Trisubstituted imidazoles

✉ Shivaji Thore, shivajiraothore@rediffmail.com | <sup>1</sup>Department of Chemistry, Vinayakrao Patil Mahavidyalaya, Vaijapur, Aurangabad, Maharashtra 423 701, India. <sup>2</sup>Department of Chemistry, Sunderrao Solunke Mahavidyalaya, Majalgaon, Dist. Beed, Maharashtra 431 131, India. <sup>3</sup>Chemical Engineering Department, National Taiwan University, Taipei 106, Taiwan. <sup>4</sup>Department of Chemistry, Deogiri College, Station Road, Aurangabad, Maharashtra 431 005, India. <sup>5</sup>Department of Biotechnology, Deogiri College, Station Road, Aurangabad, Maharashtra 431 005, India.



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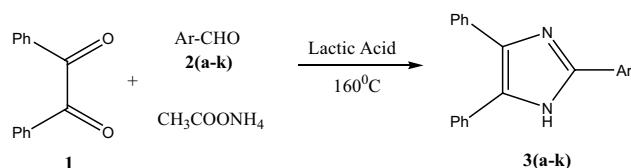
## 1 Introduction

Imidazole is an important core organic molecule. It is found in many naturally occurring compounds like vitamin B<sub>12</sub>, histidine [1], histamine, pilocarpine alkaloids, nucleic acid bases, and biotin [2–5]. Imidazole is also found to be an active part of antifungal compounds like clotrimazole, ketoconazole, miconazole, isoconazole, econazole [6]. Along with this, it is also showing good activity as herbicide [7], plant growth regulator [8], anti-epileptic [9], anticonvulsant [10], anti-inflammatory, analgesic [11], anticancer, etc. [12, 13]. Also, imidazoles are found as the main core molecule in drugs like Omeprazole, Pimobendan, Losartan, Olmesartan, Eprosartan, and Trifenagrel [14].

In organic synthesis, the product yield and reaction time are extremely important. The increase in reaction steps results in a decrease in final product yield and increase in total reaction time. Multicomponent reactions help to solve this problem. By novel developing multicomponent reaction strategies, synthesis of the desired product in the one-pot method is possible thereby increases the product yield and reducing reaction time required for the reaction. Thus, it can be considered as a greener way in organic synthesis and have attracted significant attention from many researchers in recent years [15].

Various methods are reported in the literature for the one-pot synthesis of imidazole derivatives from benzil, aromatic aldehyde, and ammonium acetate. Heterogeneous catalyst such as Lewis acids (NiCl<sub>2</sub>·6H<sub>2</sub>O [16], Ce(NH<sub>4</sub>)<sub>2</sub>(NO<sub>3</sub>)<sub>6</sub> [17], ZrCl<sub>4</sub> [18], CrCl<sub>3</sub>·6H<sub>2</sub>O [19], Pb(OAc)<sub>2</sub> [20], etc.), nano particles (MgAl<sub>2</sub>O<sub>4</sub> [21], nanorod vanadate sulfuric acid [22], magnetic Fe<sub>3</sub>O<sub>4</sub> [23], etc.) are reported for imidazole synthesis. CrCl<sub>3</sub>·6H<sub>2</sub>O and Pb(OAc)<sub>2</sub> are toxic in nature. Ionic liquids (ILs) [24–28] are also reported for the efficient synthesis of substituted imidazoles. However, ILs are expensive and recyclability of ILs are difficult [29]. Organic solvents like glycerol [30], Pr<sub>2</sub>NEt [31], PEG [32], acetic acid [33, 34], Glyoxylic acid [35], natural acids [36] are reported for the synthesis of imidazoles.

The available reported method for the synthesis of substituted imidazoles suffers from drawbacks such as the catalysts used for synthesis are either toxic or expensive and requires harsh reaction condition. To overcome these problems, we employed inexpensive, biodegradable, environmentally friendly green solvent lactic acid [37, 38] for the synthesis of 2,4,5-triaryl-1H-imidazoles. The synthesis method does not require any sophisticated assembly, and lactic acid used in this reaction acts as promoter and also solvent. Lactic acid is obtained from fermentation of carbohydrates, it is easy to handle and readily available. Lactic acid is reported as organocatalyst in several organic reactions [39–48]. In the present method we are reporting



**Fig. 1** General reaction scheme for the synthesis of 2,4,5-trisubstituted imidazole

**Table 1** Effect of solvent for the synthesis of 2,4,5-triphenyl-1H-imidazole

Entry	Lactic acid (mL)	Solvent (10 mL)	Time (min)	Temp. (°C)	Yield (%)
1	0.1	Water	180	50	37
2	0.1	Acetonitrile	180	50	30
3	0.1	Methanol	180	50	42
4	0.1	DMF	180	50	45
5	0.1	DCM	180	50	20
6	0.1	Dioxane	180	50	32
7	0.1	Ethanol	180	50	55
8	0.1	Ethanol	180	70	72
9	0.2	Ethanol	240	Reflux	72
10	0.4	Ethanol	240	Reflux	75

Benzaldehyde 1 mmol, ammonium acetate 3 mmol, benzil 1 mmol

lactic acid for the synthesis of 2,4,5-trisubstituted imidazole compounds from an aromatic aldehyde, benzil, and ammonium acetate under milder reaction conditions (160 °C) (Fig. 1).

## 2 Result and discussion

Initially, benzaldehyde was selected as a prototype for the reaction with benzil and ammonium acetate to study the catalytic activity of lactic acid. The reaction conditions were optimized to efficiently synthesize the 2,4,5-triphenyl-1H-imidazole in solvent-free condition with the catalytic amount of lactic acid, but the results were not satisfactory even at higher temperatures. Hence, we added lactic acid in various solvents and reactions were performed with different temperature (Table 1). Through the experimentation, we achieved 55% of product yield in ethanol-lactic acid system. The better results are witnessed at 70 °C (3 h) with 1:1:3 equivalent proportions of benzil, an aromatic aldehyde, and ammonium acetate, respectively.

The result shows that with an increase in the quantity of lactic acid in ethanol is not exhibiting improvement in the product yield (Table 1). Further, we conducted reactions

**Table 2** Optimization of reaction parameters for the synthesis of 2,4,5-triphenyl-1H-imidazole using lactic acid

Entry	Lactic acid (mL)	NH <sub>4</sub> OAc (mmol)	Temp. (°C)	Yield (%)
1	0.5	2	100	62
2	1.0	2	130	70
3	1.0	2.5	130	74
4	1.0	3.0	130	75
5	1.0	2.5	160	90
6	1.0	3.0	160	89
7	1.0	2.5	170	92

Benzaldehyde 1 mmol, benzil 1 mmol, 180 min

**Table 3** Comparison of natural acids for the synthesis of 2,4,5-trisubstituted imidazoles

Entry	Acid	Temp. (°C)	Time (min)	Yield (%) <sup>a</sup>
1	Citric	160	20	76 [36]
2	Fumaric	290	20	65 [36]
3	Malic	140	20	78 [36]
4	Malonic	140	20	80 [36]
5	Oxalic	110	20	77 [36]
6	Succinic	190	20	68 [36]
7	Tartaric	180	20	75 [36]
8	Lactic	160	180	92

<sup>a</sup>4-Cl- Benzaldehyde

only in the lactic acid, and the result shows an increment in the product yield in 1 mL lactic acid.

The proportions of lactic acid and ammonium acetate were varied at different temperature (Table 2). This showed the best product yield with 1 mL of lactic acid, 2.5 mmol of ammonium acetate at 160 °C (Table 2, entry 5). The obtained results were compared with other natural acids (Table 3) [36] for the synthesis of imidazoles and it shows that our method is efficient for better product yields using lactic acid.

As shown in Table 4, this catalytic system works well for both aromatic aldehydes containing electron donating and electron withdrawing groups. For 4-nitro benzaldehyde (entry f) 83% yield was obtained in 180 min while for 4-(dimethylamino)benzaldehyde 91% yield was obtained in 150 min (entry h). It means there is no specific effect of electron density on the product yield. However, the desired reaction time can be changed depending on

the type of aldehyde used for the reaction. The probable mechanism of reaction is depicted in Fig. 2.

### 3 Experimental

All the melting points were recorded by open capillary method and are uncorrected. IR spectra were recorded on Shimadzu IR Affinity 1 spectrophotometer in KBr disc. <sup>1</sup>H NMR were recorded on a BRUKER AVANCE II 400 MHz spectrometer in DMSO-d<sub>6</sub>, chemical shifts are in ppm relative to TMS. Mass spectra were taken on a Macro mass spectrometer by electron spray method (Es). The structures of various synthesized compounds were assigned on the basis of spectral studies and it has been reported in experimental protocols. The progress of reaction was monitored on Alumina coated TLC plates in ethyl acetate and n-hexane system.

**General experimental procedure:** In 10 mL round bottom flask aromatic aldehyde (1 mmol), benzil (1 mmol) and ammonium acetate (2.5 mmol) were added. To this reaction mixture, 1 mL of lactic acid was added and then reaction mixture was heated at 160 °C for an appropriate time (Table 4). The progress of reaction was monitored with the help of TLC (hexane: ethyl acetate 8:2 v/v). After completion of reaction, the mixture was poured over crushed ice (100 g and neutralized by saturated solution of sodium carbonate. The solid obtained was filtered and purified by column chromatography using hexane–ethyl acetate as eluent (9:1 v/v).

**Characterization:**

**1-(4-(4,5-diphenyl-1H-imidazol-2-yl)phenyl)piperidine (3j):**

IR (KBr, cm<sup>-1</sup>): 3080, 2880, 1600–1500

<sup>1</sup>H NMR (400 MHz, DMSO-d<sub>6</sub>, δ, ppm): 1.56–1.62 (m, 6H, 3CH<sub>2</sub>), 3.21–3.23 (t, 4H, 2CH<sub>2</sub>), 6.99 (d, J = 8 Hz, 2H, Ar-H), 7.21–7.55 (m, 10H, Ar-H), 7.94 (d, J = 8 Hz, 2H, Ar-H), 12.29 (s, 1H, NH)

<sup>13</sup>C NMR (100 MHz, DMSO-d<sub>6</sub>): 23.90, 25.10, 48.87, 114.98, 120.24, 126.25, 127.05, 127.38, 128.08, 128.24, 128.52, 129.49, 129.55, 131.31, 135.52, 136.59, 146.19, 151.23

ESI-MS (m/z): 379.49 (M + 1)

**4,5-diphenyl-2-(4-(pyrrolidin-1-yl)phenyl)-1H-imidazole (3k):**

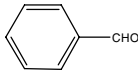
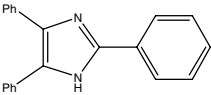
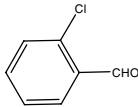
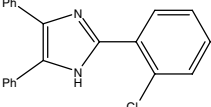
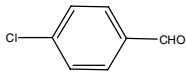
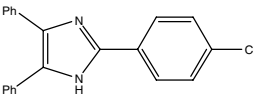
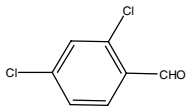
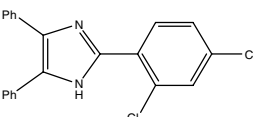
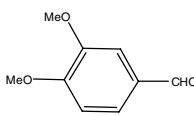
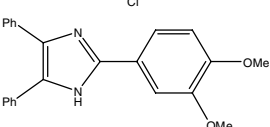
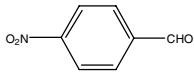
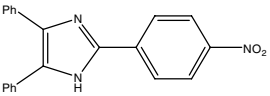
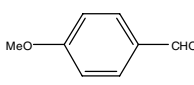
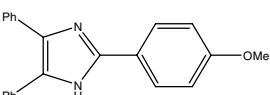
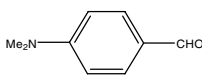
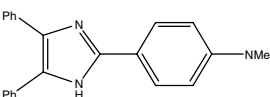
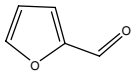
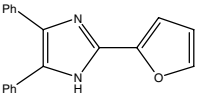
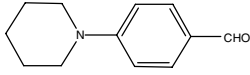
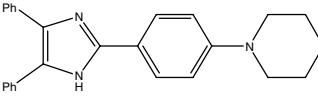
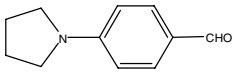
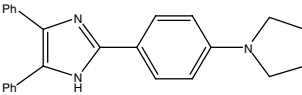
IR (KBr, cm<sup>-1</sup>): 3100, 2930, 1600–1500

<sup>1</sup>H NMR (400 MHz, DMSO-d<sub>6</sub>, δ, ppm): 1.96 (t, 4H, 2CH<sub>2</sub>), 3.28 (t, 4H, 2CH<sub>2</sub>), 6.61 (d, J = 8 Hz, 2H, Ar-H), 7.20–7.56 (m, 10H, Ar-H), 7.91 (d, J = 8 Hz, 2H, Ar-H), 12.29 (s, 1H, NH)

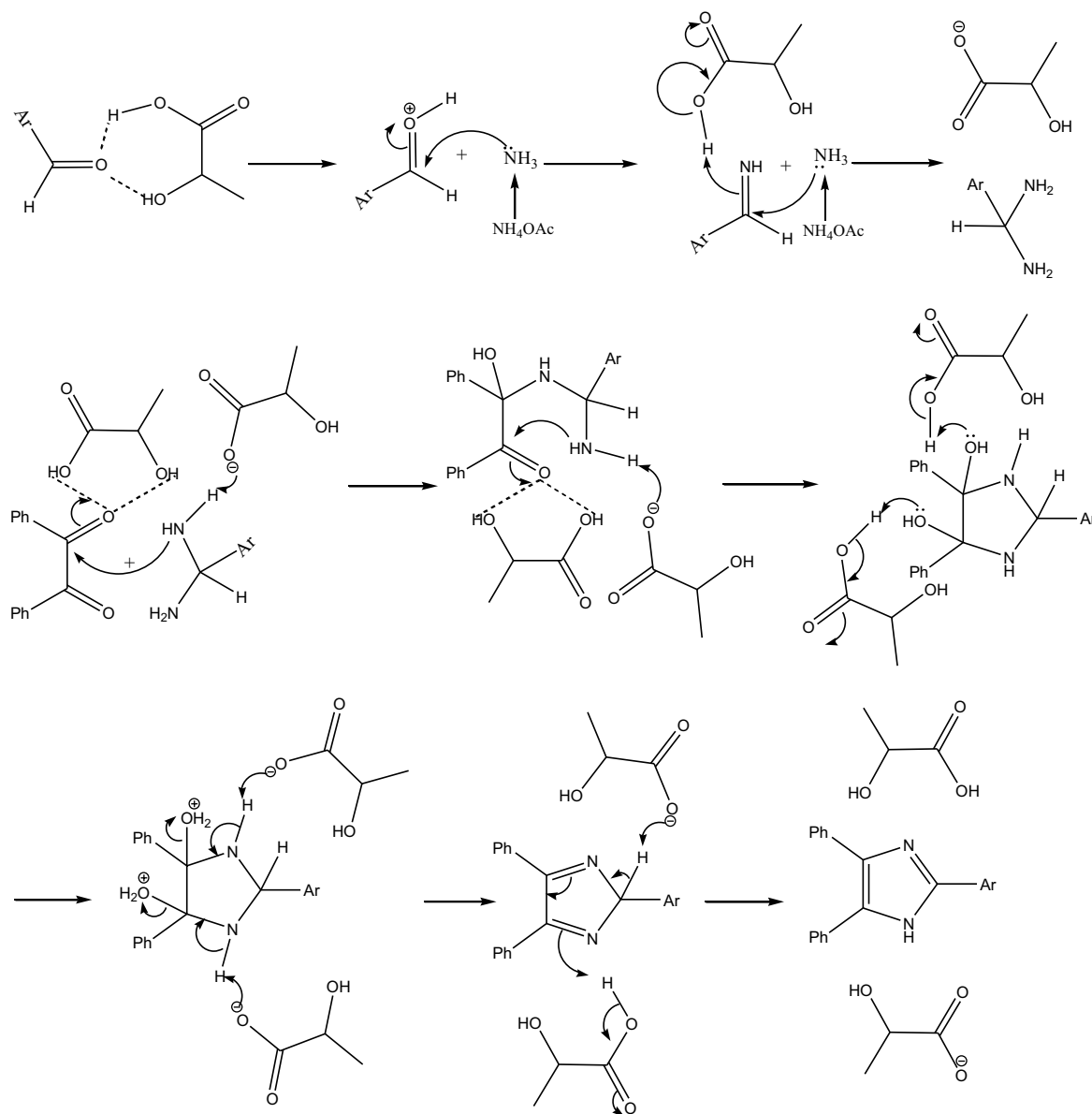
<sup>13</sup>C NMR (100 MHz, DMSO-d<sub>6</sub>): 24.95, 47.21, 11.37, 117.52, 126.20, 126.41, 126.89, 127.03, 127.30, 128.06, 128.21, 128.52, 131.46, 135.60, 136.45, 146.71, 147.59

ESI-MS (m/z): 365.4 (M + 1)

**Table 4** Synthesis of 2,4,5-trisubstituted imidazoles 3(a–k) using lactic acid<sup>a</sup>

Entry	Aldehyde 2(a–k)	Product 3(a–k)	Time (min)	Yield (%)	Melting points (°C)	
					Obs.	References
a.			180	90	275–276	278 [47]
b.			180	94	190–192	194–196 [47]
c.			180	92	262–263	263–264 [47]
d.			180	85	172–174	174–176 [47]
e.			150	89	220–221	217–219 [48]
f.			180	83	225	225–227 [47]
g.			170	90	230	230–232 [47]
h.			150	91	257–259	260–261 [49]
i.			150	84	240	237–238 [50]
j.			150	92	215–216	–
k.			150	90	220–221	–

<sup>a</sup>Aromatic aldehyde 1 mmol, ammonium acetate 2.5 mmol, benzil 1 mmol, lactic acid 1 mmol, temperature 160 °C



**Fig. 2** Plausible mechanism for the synthesis of 2,4,5-trisubstituted imidazoles using lactic acid

## 4 Conclusion

Herein we are reporting the efficient method using inexpensive, biodegradable and environmental benign green solvent for the synthesis of 2,4,5-trisubstituted imidazole. This method provides a better performance and higher product yield for aromatic aldehydes containing electron donating and electron withdrawing groups.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.



## References

1. Kumar V, Kaur K, Gupta GK, Sharma AK (2013) Pyrazole containing natural products: synthetic preview and biological significance. *Eur J Med Chem* 69:735–753. <https://doi.org/10.1016/j.ejmech.2013.08.053>
2. Kumar V, Mahajan MP (2011) In: Majumdar KC, Chattopadhyay SK (eds) *Heterocycles in natural product synthesis*. Pyrimidine and imidazole. Wiley-VCH, Weinheim, pp 507–533. <https://doi.org/10.1002/9783527634880.ch14>
3. Azizi SN, Shakeri P, Chaichi MJ, Bekhradnia A, Taghavi M, Ghaemy M (2014) The use of imidazolium ionic liquid/copper complex as novel and green catalyst for chemiluminescent detection of folic acid by Mn-doped ZnS nanocrystals. *Spectrochim Acta Part A* 122:482–488. <https://doi.org/10.1016/j.saa.2013.11.036>
4. Arshadi S, Bekhradnia AR, Ebrahimnejad A (2011) Feasibility study of hydrogen-bonded nucleic acid base pairs in gas and water phases—a theoretical study. *Can J Chem* 89:1403–1409. <https://doi.org/10.1139/v11-124>
5. Vessally E, Soleimani-Amiri S, Hosseinian A, Edjlalid L, Bekhradnia A (2017) New protocols to access imidazoles and their ring fused analogues: synthesis from N-propargylamines. *RSC Adv* 7:7079–7091. <https://doi.org/10.1039/c6ra25816f>
6. Bastide M, Jouvert S, Bastid JM (1982) A comparison of the effects of several antifungal imidazole derivatives and polyenes on *Candida albicans*: an ultrastructural study by scanning electron microscopy. *Can J Microbiol* 28(10):1119–1126. <https://doi.org/10.1139/m82-166>
7. Maier T, Schmierer R, Bauer K, Bieringer H, Buerstell H, Sachse B (1989) 1-substituted imidazole-5-carboxylic acid derivatives, their preparation and their use as biocides. U. S. Patent 4 820 335, 1989, *Chem. Abstr.*, 1989, 111, 19494w
8. Schmierer R, Mildenerger H, Buerstell H (1987) German Patent 361464, *Chem. Abstr.*, (1988) 108: 37838
9. Mishra R, Ganguly S (2012) Imidazole as an anti-epileptic: an overview. *Med Chem Res* 21(12):3929–3939. <https://doi.org/10.1007/s00044-012-9972-6>
10. Robertson DW, Beedle EE, Lawson R, Leander JD (1987) Imidazole anticonvulsants: structure-activity relationships of [(biphenyloxy)alkyl]imidazoles. *J Med Chem* 30(5):939–943. <https://doi.org/10.1021/jm00388a035>
11. Puratchikodya A, Doble M (2007) Antinociceptive and anti-inflammatory activities and QSAR studies on 2-substituted-4,5-diphenyl-1H-imidazoles. *Bioorg Med Chem* 15:1083–1090. <https://doi.org/10.1016/j.bmc.2006.10.025>
12. Ali I, Lone MN, Aboul-Enein HY (2017) Imidazoles as potential anticancer agents. *Med Chem Commun* 8:1742–1773. <https://doi.org/10.1039/c7md00067g>
13. Baroniya S, Anwer Z, Sharma PK, Dudhe R, Kumar N (2010) Recent advancement in imidazole as anti-cancer agents: a review. *Der Pharm Sin* 1(3):172–182
14. Abrahams SL, Hazen RJ, Batson AG, Phillips AP (1989) Trifenagrel: a chemically novel platelet aggregation inhibitor. *J Pharm Exp Therap* 249(2):359–365
15. Cioc RC, Ruijter E, Orru RVA (2014) Multicomponent reactions: advanced tools for sustainable organic synthesis. *Green Chem* 16:2958–2975. <https://doi.org/10.1039/c4gc00013g>
16. Heravi MM, Bakhtiari K, Oskooie HA, Taheri S (2007) Synthesis of 2,4,5-triaryl-imidazoles catalyzed by NiCl<sub>2</sub>·6H<sub>2</sub>O under heterogeneous system. *J Mol Cat A* 263:279–281. <https://doi.org/10.1016/j.molcata.2006.08.070>
17. Sangshetti JN, Kokare ND, Kotharkara SA (2008) Shinde DB (2008) Ceric ammonium nitrate catalysed three component one-pot efficient synthesis of 2,4,5-triaryl-1H-imidazoles. *J Chem Sci* 120(5):463–467. <https://doi.org/10.1007/s12039-008-0072-6>
18. Sharma GVM, Jyothi Y, Lakshmi PS (2006) Efficient room-temperature synthesis of Tri- and tetrasubstituted imidazoles catalyzed by ZrCl<sub>4</sub>. *Synth Commun* 36:2991–3000. <https://doi.org/10.1080/00397910600773825>
19. Karami B, Eskandari K, Farahi M, Barmas A (2012) An effective and new method for the synthesis of polysubstituted imidazoles by the use of CrCl<sub>3</sub>·6H<sub>2</sub>O as a green and reusable catalyst: synthesis of some novel imidazole derivatives. *J Chin Chem Soc* 59:473–479. <https://doi.org/10.1002/jccs.201100555>
20. Patil VD, Sutar NR, Patil KP, Giddh P (2016) Synthesis of 2,4,5-triaryl-1H-imidazoles using anhydrous Pb(OAc)<sub>2</sub> as a catalyst in C<sub>2</sub>H<sub>5</sub>OH. *Der Chem Sin* 7(2):23–28
21. Safari J, Akbari Z, Naseh S (2016) Nanocrystalline MgAl<sub>2</sub>O<sub>4</sub> as an efficient catalyst for one-pot synthesis of multisubstituted imidazoles under solvent-free conditions. *J Saudi Chem Soc* 20(1):S250–S255. <https://doi.org/10.1016/j.jscs.2012.10.012>
22. Nasr-Esfahani M, Montazerzohori M, Abdizadeh T (2015) Multi-component synthesis of highly substituted imidazoles catalyzed by nanorod vanadatesulfuric acid. *Chem Pap* 69(11):1491–1499. <https://doi.org/10.1515/chempap-2015-0156>
23. Karami B, Eskandari K, Ghasemi A (2012) Facile and rapid synthesis of some novel polysubstituted imidazoles by employing magnetic Fe<sub>3</sub>O<sub>4</sub> nanoparticles as a high efficient catalyst. *Turk J Chem* 36:601–614. <https://doi.org/10.3906/kim-1112-49>
24. Marzouk AA, Abbasov VM, Talybov AH, Mohamed SK (2013) Synthesis of 2,4,5-triphenyl imidazole derivatives using diethyl ammonium hydrogen phosphate as green, fast and reusable catalyst. *World J Org Chem* 1(1):6–10. <https://doi.org/10.12691/wjoc-1-1-2>
25. Khosropour AR (2008) Synthesis of 2,4,5-trisubstituted imidazoles catalyzed by [Hmim]HSO<sub>4</sub> as a powerful Brønsted acidic ionic liquid. *Can J Chem* 86:254–269. <https://doi.org/10.1139/v08-009>
26. Xia M, Lu Y-D (2007) A novel neutral ionic liquid-catalyzed solvent-free synthesis of 2,4,5-trisubstituted imidazoles under microwave irradiation. *J Mol Catal A Chem* 265(1–2):205–208. <https://doi.org/10.1016/j.molcata.2006.10.004>
27. Chary MV, Keerthysri NC, Vupallapati SVN, Lingaiah N, Kantevari S (2008) Tetrabutylammonium bromide (TBAB) in isopropanol: an efficient, novel, neutral and recyclable catalytic system for the synthesis of 2,4,5-trisubstituted imidazoles. *Catal Commun* 9(10):2013–2017. <https://doi.org/10.1016/j.catcom.2008.03.037>
28. Shaabani A, Rahmati A, Aghaaliakbari B, Safaei-Ghomi J (2006) 1,1,3,3-N, N, N', N'-tetramethylguanidinium trifluoroacetate ionic liquid promoted efficient one-pot synthesis of trisubstituted imidazoles. *Synth Commun* 36:65–70. <https://doi.org/10.1002/chin.200623121>
29. Matsagar BM, Hossain SA, Islam T, Alamri HR, Alothman ZA, Yamauchi Y, Dhepe PL, Wu KC-W (2017) Direct production of furfural in one-pot fashion from raw biomass using Brønsted acidic ionic liquids. *Sci Rep* 7(1):1–7. <https://doi.org/10.1038/s41598-017-13946-4>
30. Nemati F, Hosseini MM, Kiani H (2016) Glycerol as a green solvent for efficient, one-pot and catalyst free synthesis of 2,4,5-triaryl and 1,2,4,5-tetraaryl imidazole derivatives. *J Saudi Chem Soc* 20:S503–S508. <https://doi.org/10.1016/j.jscs.2013.02.004>
31. Chen Y, Wang R, Ba F, Hou J, Ding A, Zhou M, Guo H (2017) Synthesis of 2,4,5-triarylated imidazoles via three-component domino reaction under catalyst-free conditions. *J Saudi Chem Soc* 21(1):76–81. <https://doi.org/10.1016/j.jscs.2016.03.001>
32. Nalage SV, Kalyankar MB, Patil VS, Bhosale SV, Deshmukh SU, Pawar RP (2010) An efficient noncatalytic protocol for the synthesis of trisubstituted imidazole in polyethylene glycol using

- microwaves. *Open Cat J* 3:58–61. <https://doi.org/10.2174/1876214x01003010058>
33. Li J-T, Chen B-H, Yan-Wei L, Xue-Li S (2012) Efficient Improved Synthesis of 2-Aryl-4,5-diphenylimidazole by Heating. *Int J Adv Pharm Biol Chem* 1(3):287–292
34. Shivani P, Sudhakar A, Gosh S (2013) One pot synthesis of tri and tetra substituted imidazole derivatives. *Int J Pharm Biol Sci* 3(4):270–277
35. Shelke K, Kakade G, Shingate B, Shingare M (2008) Microwave-induced one-pot synthesis of 2,4,5-triarylimidazoles using glyoxylic acid as a catalyst under solvent-free conditions. *Ras J Chem* 1(3):489–494
36. Dhawale KD, Thorat NM, Patil LR (2017) An efficient and green synthesis of imidazoles using natural organic acids as promoter under solvent-free condition. *Asian J Chem* 29(8):1709–1712. <https://doi.org/10.14233/ajchem.2017.20553>
37. Häckl K, Kunz W (2018) Some aspects of green solvents. *C R Chimie* 21(6):572–580. <https://doi.org/10.1016/j.crci.2018.03.010>
38. Yang J, Tan J-N, Gu Y (2012) Lactic acid as an invaluable bio-based solvent for organic reactions. *Green Chem* 14:3304–3317. <https://doi.org/10.1039/c2gc36083g>
39. Suresh Saini A, Kumar D, Sandhu JS (2009) Multicomponent eco-friendly synthesis of 3,4-dihydropyrimidine-2-(1H)-ones using an organocatalyst Lactic acid. *Green Chem Lett Rev* 2(1):29–33. <https://doi.org/10.1080/17518250902973833>
40. Kangani M, Hazeri N, Maghsoodlou MT (2017) Synthesis of pyrrole and furan derivatives in the presence of lactic acid as a catalyst. *J Saudi Chem Soc* 21(2):160–164. <https://doi.org/10.1016/j.jscs.2015.03.002>
41. Zhaleh S, Hazer N, Maghsoodlou MT (2016) Green protocol for synthesis of 2,3-dihydroquinazolin-4(1H)-ones: lactic acid as catalyst under solvent-free condition. *Res Chem Intermed* 42(7):6381–6390. <https://doi.org/10.1007/s11164-016-2469-z>
42. Sadeh FN, Hazeri N, Maghsoodlou MT, Lashkari M (2017) Efficient lactic acid-catalyzed route to naphthopyranopyrimidines under solvent-free conditions. *Org Prep Proced Int* 49:35–44. <https://doi.org/10.1080/00304948.2017.1260395>
43. Adrom B, Hazeri N, Maghsoodlou MT, Lashkari M, Fatahpour M (2017) Green synthesis of 2-aryl-4-phenyl-quinazoline derivatives promoted by lactic acid. *Maced J Chem Chem Eng* 36(2):223–228. <https://doi.org/10.20450/mjccce.2017.1137>
44. Adrom B, Hazeri N, Maghsoodlou MT, Lashkari M, Fatahpour M (2017) Green synthesis of 2-aryl-4-phenyl-quinazoline derivatives promoted by lactic acid. *Maced J Chem Chem Eng* 36(2):223–228. <https://doi.org/10.20450/mjccce.2017.1137>
45. Kangani M, Hazeri N, Yazdani-Elah-Abadi A, Maghsoodlou MT (2016) Lactic acid: an efficient and green catalyst for the one-pot five-components synthesis of highly substituted piperidines. *Polycycl Aromat Compd*. <https://doi.org/10.1080/10406638.2016.1207686>
46. Wagh RB, Nagarkar JM (2018) An efficient and sustainable protocol for oxidation of alcohols to carbonyl compounds. *Tetrahedron Lett* 59(37):3443–3447. <https://doi.org/10.1016/j.tetlet.2018.08.011>
47. Wang R, Liu C, Luo G (2010) A convenient synthesis of 2,4,5-triarylimidazoles catalyzed by Y(TFA)<sub>3</sub>. *Green Chem Lett Rev* 3(2):101–104. <https://doi.org/10.1080/17518250903583680>
48. Maleki B, Ashrafi SS (2014) N-Bromosuccinimide Catalyzed three component one-pot efficient synthesis of 2,4,5-triaryl-1H-imidazoles from aldehyde, ammonium acetate, and 1,2-diketone or  $\alpha$ -hydroxyketone. *J Mex Chem Soc* 58(1):76–81. <https://doi.org/10.29356/jmcs.v58i1.159>
49. Safari J, Naseh S, Zarnegar Z, Akbari Z (2014) Applications of microwave technology to rapid synthesis of substituted imidazoles on silica-supported SbCl<sub>3</sub> as an efficient heterogeneous catalyst. *J Taibah Univ Sci* 8:323–330. <https://doi.org/10.1016/j.jtusci.2014.01.007>
50. Nikoofar K, Dizgarani SM (2017) HNO<sub>3</sub>@nano SiO<sub>2</sub>: an efficient catalytic system for the synthesis of multi-substituted imidazoles under solvent-free conditions. *J Saudi Chem Soc* 21(7):787–794. <https://doi.org/10.1016/j.jscs.2015.11.006>

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