SYNTHESIS AND CHARACTERIZATION OF A PHENYL IMIDAZOLE DERIVATIVE USING A GREEN CHEMISTRY METHOD

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ABSTRACT

Imidazole derivatives make up a significant antioxidant of heterocyclic compounds which have been applied in pharmaceuticals, in materials science and in organic synthesis extensively. The work being reported here is the synthesis and characterization of 2-(2-nitrophenyl)-4,5-diphenyl-1H-imidazole via green chemistry method, a method designed to minimize the usage of the solvents, to reduce waste and to increase the efficiency of the reaction. The synthesis was performed utilizing benzil, 2-nitrobenzaldehyde and ammonium acetate at low temperatures, giving the target compound with the unbeatable yield of 97.29%. The recrystallization purification led to the formation of a light yellow-green amorphous solid that was stable. The new compound was examined using physicochemical and spectroscopic methods. The MP (160°C) was indicative of the new compound being different from the reactants. The solubility tests showed that it was soluble in acetone only, which reflects the changes in the structure that are attributed to the formation of the imidazole ring. The TLC suggested R_f of 0.83, thus confirming the identity and purity of the compound. UV–Vis showed a λ_{max} at 325 nm, which is a slight shift compared to benzil and confirming the changes in the conjugated system. FT-IR provided supportive evidence for the molecule's construction by giving the specific vibrational peaks representing the phenylic, nitro, and the imidazole parts of the structure. In general, the results provide evidence that green chemistry delivers an effective, quick, and sustainable pathway for the production of phenyl imidazole derivatives. Thus, it is not only less damaging to the environment but also in line with the modern doctrines of eco-friendly chemical synthesis, which makes it a significant alternative for the development of heterocyclic compounds in both research and pharmaceutical applications.

Keywords

Imidazole derivative; Green chemistry; Heterocyclic synthesis; Spectroscopic characterization; TLC; FT-IR; UV–Vis analysis

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1. INTRODUCTION

Imidazole, being a heterocyclic compound, is still at the centre of much research mainly because of its wide range of chemical uses and its importance in medicine. This structure, composed of five alternating carbon and nitrogen atoms, attracts attention owing to its unique structural and electronic features which are imparted by the presence of nitrogen atoms [1]. Once the compound was produced by the reaction of glyoxal and ammonia; hence it was called "glyoxaline," imidazole turned out to be a multipurpose compound since it was able to form both acids and bases, it was also able to undergo hydrogen bonding, and it was very stable under various extreme conditions like acids, bases, high temperatures, accidental or intentional oxidation and reduction. Its tautomeric flexibility due to the migration of protons between the two nitrogen atoms enhances the reactivity and synthetic utility even more [2]. Based on these beneficial properties, imidazole derivatives have been actively researched in the area of drugs. A lot of reports on the studies indicate their role in the development of drugs against cancer, antioxidants, inflammation, gastroprotective, histamine H3 antagonist, antimycotic, and antiparasitic agents [3]. Throughout the history of synthetic organic chemistry, several classical synthetic routes such as Debus, Radiszewski, and Marckwald methods have become the dependable strategies for the formation of the imidazole ring, and at the same time, procedures involving α-halo ketones, imidazolines, aminonitriles, and aldehyde condensations were considered as more reliable [4]. Nevertheless, the prevailing methods of synthesis still require harsh conditions, and they still use toxic reagents, large solvents and long reaction times, which are all listed among the main factors contributing to such usages. This practice raises the energy consumption and operation costs significantly, besides it being also a source of chemical waste and environmental hazards. With the world getting more and more aware of the need for sustainability and ecological responsibility, the chemical sciences have gradually been turning to green chemistry, a practice that is aimed at cutting down or totally getting rid of hazardous waste in chemical operations [5,6]. The concept of green chemistry was officially recognized by Paul Anastas in the 1990s with the aim to guide the development of chemical practices that are safe, efficient, and environmentally friendly [7]. From that time, the movement has progressed into a worldwide initiative that is being diligently supported by the scientific community, funding agencies, educational institutions, and industries all collaborating towards making sustainability the new norm in chemical research [8]. The Twelve Principles of Green Chemistry are the mainstay of this method, offering an all-encompassing guideline for the development of eco-friendly chemical processes. Waste prevention is one of the key points of these principles [10,11], and the improvement of atom economy ensures that all the atoms from the reactants are incorporated into the final product in a very efficient manner [12]. Moreover, the principles talk about the reduction of chemical toxicity [13] and the creation of safe chemical products with the same level of performance as current ones [14]. Besides, they recommend avoiding or minimizing the use of harmful solvents and other substances [15], and making the use of energy more efficient by moving to lower reaction temperatures or using alternative energy sources [16,17]. In addition, renewable raw materials like biomass should be used as much as possible [18]. Among other things, the principles also warn against unnecessarily adding or modifying substances to eliminate waste which is not really necessary [19], and they also recommend using catalytic systems instead of stoichiometric reagents in the chemical processes [20]. They even propose the making of chemicals and products designed to degrade safely after use [21]. Moreover, constant monitoring of chemical reactions is necessary to prevent the production of hazardous by-products [22], the implementation of strong safety measures to minimize risks associated with chemical processes is required [23]. The imidazole derivatives are of great biological importance and at the same time very promising in the field of pharmaceuticals. For this reason, the characterization of such compounds is also very necessary. The analytical methods simultaneously employed were thin-layer chromatography (TLC), Fourier-transform infrared spectroscopy (FT-IR), and ultraviolet-visible (UV-Vis) spectroscopy that have been critical for proving the structure, detecting the functional groups, and assessing the purity of the samples. Furthermore, these methods provide a faster, more reliable, and more accurate evaluation with respect to traditional techniques such as melting and solubility point analysis [24]. In that respect, the present study accentuates the syntheses and characterization of a phenyl imidazole

derivative based on green chemistry, with environmental sustainability as the main aim and at the same time ensuring the efficiency and the quality of the product.

2. MATERIALS AND METHODS

2.1 Materials

Benzil, 2-nitrobenzaldehyde, ammonium acetate, and glacial acetic acid were sourced from Sigma-Aldrich and Merck. Acetone and other analytical solvents were obtained from SD Fine Chemicals. All reagents were of the analytical grade and were used without further purification. Some auxiliary chemicals were donated as gift samples from a nearby research laboratory.

2.2 Synthesis of Phenyl Imidazole Derivative (Green Chemistry Method)

Green chemistry technique was used for the synthesis of 2-(2-nitrophenyl)-4,5-diphenyl-1H-imidazole. The first step was to take a clean 250 mL beaker, mix in it 2.5 g of benzil and 1.5 g of 2-nitrobenzaldehyde. One more compound, ammonium acetate, weighing 5 g was added to the mixture and mixed thoroughly with a glass rod. With constant stirring, 40 mL of glacial acetic acid was added to the vessel, while the reactant mass came to be homogeneous. The reactor mass was then microwaved at 90°C for 150 seconds, with brief manual mixing every 50 seconds to guarantee the heat distribution is uniform. At the end, the mixture was allowed to cool down to room temperature, and then 150 mL of cold distilled water was added to the mixture which was intended to make the product precipitate. The formed solid was collected through vacuum filtration, washed, and dried first with an hour in a hot-air oven and then at room temperature. The raw product was recrystallized from acetone for purification, and the final phenyl imidazole derivative was obtained as a solid suitable for further characterization.

Calculation of percentage yield by green chemistry method

- Molecular weight of Benzil = 210.23gm/mol
- Molecular weight of 2-(2-nitrophenyl)-4,5-diphenyl-1H- imidazole = 341.36gm/mol
- Weight of reactant taken (Benzil) = 2.5gm
- Practical yield = 3.95gm

$$Theoretical\ yield = \frac{Molecular\ weight\ of\ phenyl\ imidazole\ X\ Weight\ of\ benzil\ taken}{Molecular\ weight\ of\ benzil}$$

$$Theoretical\ yield = \frac{341.36gm/mol\ X\ 2.5gm}{210gm/mol}$$

Theoretical yield = 4.06gm

$$Percentage\ yield = \frac{Practical\ yield}{Theoretical\ yield} \times 100$$

$$Percentage\ yield = \frac{3.95}{4.06} \times 100$$

Percentage yield = 97.29%

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics: The compound obtained through the green chemistry method was phenyl imidazole derivative, and it was studied for its physical and analytical properties. The results are given in Table 1.

Table 1. Physical & analytical data of the phenyl imidazole derivative by green chemistry method

Compound name	% yield	Molecular Formula	Molecular Weight	C	H	O	N
2-(2-nitrophenyl)-4,5-diphenyl imidazole	97.29%	$C_{21}H_{15}N_3O_2$	341.36 g/mol	73.90%	4.43%	12.32%	9.37%

The final product appeared as light yellow-green, faintly odoriferous and amorphous powder as shown in Table 2.

Table 2. Physical evaluation of the phenyl imidazole derivative by green chemistry method

Synthesis of phenyl imidazole derivative	Colour	Odor	Texture
Green chemistry method	Light yellow-green	Faint	Amorphous powder

Fig 1: Obtained phenyl imidazole derivative powder through green chemistry method

The new heterocyclic structure or the formation of trace impurities during the reaction may be the reasons for the color difference of the starting materials. (Fig 1) The lack of a strong odor indicates the presence of very few volatile contaminants. The amorphous texture refers to a non-crystalline, uniformly distributed solid, which is another reason to believe that the compound was successfully formed.

The melting point of the synthesized derivative was 160 °C, which is quite a bit higher compared to that of benzil (94 °C). This drastic change is clear evidence for the formation of a new compound and it rules out the possibility of unreacted benzil being there.

3.2 Solubility Profile

Solubility testing showed clear differences between benzil and the synthesized derivative (Table 3).

Table 3. Solubility of standard benzil and green chemistry method

Organic Solvent	Standard Benzil	Green Chemistry Method
Water	Not Soluble	Not Soluble
Ethanol	Soluble	Not Soluble
Methanol	Soluble	Not Soluble
Acetone	Freely Soluble	Freely Soluble
Chloroform	Chloroform	Not Soluble

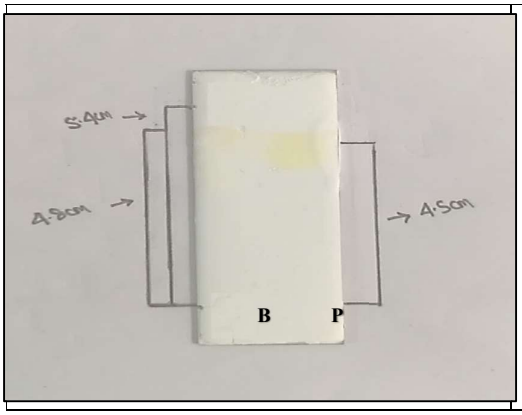
Benzil proved its good solubility in different organic solvents, on the other hand the prepared imidazole derivative was the only one that melted in acetone. Such a restricted solubility pattern matches with the

scenario of increasing aromaticity and straining of the structure due to ring formation.

3.3 Thin-Layer Chromatography (TLC)

TLC was applied to analyze the purity of the product and to differentiate it from the raw materials. The compound obtained showed an Rf value of 0.83, whereas under the same chromatographic conditions, benzil had an Rf value of 0.88.

The Rf values are near to each other, this is a consequence of the similar aromatic structures however, the slight alteration still acts as a proof of the imidazole structure formation and the accomplishment of the conversion of reactants.(Fig 2)



$$Rf\ value = \frac{Distance\ travelled\ by\ solute}{Distance\ travelled\ by\ solvent}$$

$$Rf\ value\ of\ product = \frac{4.5}{5.4} = 0.83$$

$$Rf\ value\ of\ benzil = \frac{4.8}{5.4} = 0.88$$

Fig 2: Thin layer chromatography of green chemistry method

3.4 UV–Visible Spectroscopy

The UV–Vis spectra of benzil and the synthesized derivative are presented in Table 4.

Table 4. UV–Vis λmax values

Sample	λmax (nm)	Absorbance
Benzil	331	0.168
Synthesized derivative	325	0.103

The imidazole ring formation leads to the shift of the conjugated system and thus a decrease in λmax to 325 nm for the synthesized derivative whereas benzil has λmax of 331 nm. The decrease in the absorbance found in the synthesized derivative supports the idea of performed electronic transitions and reveals the occurrence of the structural transformation.

3.5 FT-IR Spectroscopy

FT-IR analysis was carried out using an ATR setup. The significant absorption bands are listed in Table 5.

Table 5. FT-IR interpretation of the synthesized compound

Wavenumber (cm^{-1})	Intensity	Assignment
870.3	0.814	Aromatic (phenyl) C–H bending
1302.7	0.776	Nitro (NO_2) stretching
1399.6	0.758	Imidazole ring (C=N, C=C) vibrations

The FT-IR spectrum indicated the presence of characteristic vibrations of the phenyl ring in the range of 690–900 cm^{-1}, very strong peaks of the nitro group in the range of 1290–1360 cm^{-1}, and imidazole C=N/C=C absorption in the range of 1400–1600 cm^{-1}. This collection of vibrational patterns is in line with the anticipated structure of 2-(2-nitrophenyl)-4,5-diphenyl imidazole, thereby confirming the successful synthesis of the target compound.

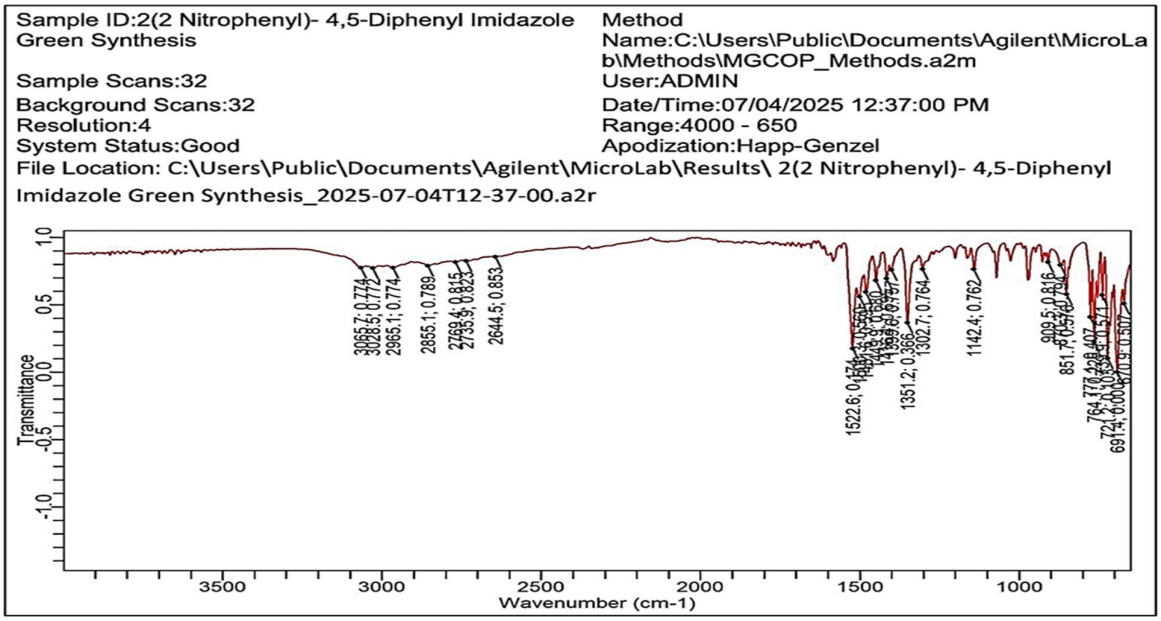


Fig 3: FT-IR analysis

4. CONCLUSION

In this research, a green chemistry–based method was utilized to an excellent end, as it succeeded in making 2-(2-nitrophenyl)-4,5-diphenyl-1H-imidazole, hence proving that derivatives of imidazole are capable of being made under non-harmful conditions very efficiently. A rapid process, with the use of a very small amount of solvent, resulted in the production of 97.29% as the very good yield of the green synthetic protocol, thus its effectiveness was revealed. Extensive characterization, comprising melting point, solubility, TLC, UV–Vis spectroscopy, and FT-IR analysis verified both the identity and the purity of the compound synthesized. The melting point was significantly raised in comparison to benzil, and its selective solubility profile provided conclusive evidence of the new heterocyclic structure formed. The TLC Rf value (0.83), which was at the same time very near to and yet different from that of benzil, verified the change of structure. The maximal UV-Vis λ of 325 nm indicated the switching of the conjugated system which was consistent with the opening of the imidazole ring.The FT-IR spectra showed the characteristic vibrational peaks of phenyl, nitro, and imidazole, thus supporting the anticipated molecular structure once again.

In general, the green synthetic method has been as clean, efficient, and sustainable as a traditional imidazole synthesis alternative. The process worked in a way that it cut down the reaction time, and waste production to a minimum, and provided the reagents that were not so harsh, which is very much in line with the modern principles of green chemistry. Such results present the environmental friendly methods as a great potential source of heterocyclic compounds and strengthen their necessity in pharmaceutical and organic chemistry research.

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