

A Green Chemical Synthesis of 2-Alkylbenzimidazoles from 1,2-Phenylenediamine and Propylene Glycol, or Alcohols Mediated by Ag-TiO₂/Clay Composite Photocatalyst

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Benzimidazole derivatives were synthesized in good yield from 1,2-phenylenediamine (PD) and various alcohols by photocatalytic cyclization with TiO₂/acidic clay composite catalyst using UV-A and solar light. Doping silver on TiO₂ enhances product yield and selectivity of the photocatalytic synthesis of benzimidazoles. The higher efficiency of nano-Ag-doped TiO₂ in solar light makes this synthesis a green chemical process.

Benzimidazole and its derivatives are important class of bioactive molecules in the field of drugs.¹ The classical synthesis of benzimidazole and its derivatives involves the facile condensation of aromatic *o*-diamine and carbonyl compounds under strong acidic, or harsh dehydrating conditions.² A number of photocatalytic chemical transformations using semiconductor particles (CdS and TiO₂) have been reported.^{3,4} Combining the photocatalytic activity of TiO₂ with utility of zeolites for photo-induced cyclisation is advantageous⁵ because this integrated photocatalyst absorbent matrix utilizes absorption with advanced oxidation by photocatalyst. Performance of these photocatalysts has been improved to extend their light absorption and conversion capacity to the visible region of the solar spectrum.⁶ In our laboratory, we had investigated the use of these modified photocatalysts in wastewater detoxification.⁷

In the present work, we report a simple ecofriendly intermolecular cyclization of 1,2-phenylenediamine (PD) with propylene glycol (PG) or primary alcohols in the presence of TiO₂, Ag-TiO₂/acidic clay (K10 montmorillonite), and air.^{8,13} It was reported earlier that composite catalyst TiO₂-acidic zeolite induced a photocatalytic cyclization of PD and propylene glycol resulting in the formation of 2-methylquinoxaline and quinoxaline.⁹ To the best of our knowledge, this paper describes for the first time the synthesis of 2-alkylbenzimidazoles under mild conditions using solar light.

We first investigated the photocatalytic cyclization reaction of PD with PG using UV-A or solar light under different conditions. The results are presented in Table 1. It was observed that photocatalytic formation of 2-methylbenzimidazole (2MBZ) and benzimidazole (BZ) from PG with PD required light, TiO₂, acidic clay, and air for higher yield. When carried out using conventional liquid acid (HCl) or clay without TiO₂ the reaction did not yield any product. However, PD and PG when irradiated with TiO₂ under similar conditions, a small amount of 2MBZ (14%) was formed.

With TiO₂/clay (2%) composite catalyst 48% of 2MBZ and 18% BZ were formed on irradiation by UV-A light. When the percentage of clay was increased to 5%, 60% of 2MBZ and 30% of BZ were formed. Whereas in solar light 58% of 2MBZ and 30% of BZ were formed on 10 h irradiation. Further change in the percentage of clay or TiO₂ in the TiO₂/clay (5%) did not give better yield. Hence TiO₂/acidic clay (5%) was

Table 1. Photocatalytic cyclization of 1,2-phenylenediamine with propylene glycol under different conditions

Conditions ^a	Irr. time	2MBZ	BZ	Conversion
	/h	/%	/%	/%
Clay/TiO ₂ /dark/air	8	0	0	0
TiO ₂ /air/light	8	14	3	17
Clay/air/light	8	0	0	0
TiO ₂ /clay (2%)/air/light	8	48	18	66
TiO ₂ /clay (5%)/air/light	8	60	30	90
TiO ₂ /clay (5%)/air/solar light	10	58	30	88

^aAll reactions were performed with a mole ratio of (1:2) in acetonitrile (20 mL) solvent. TiO₂ = 200 mg, airflow = 8.1 mL s⁻¹.

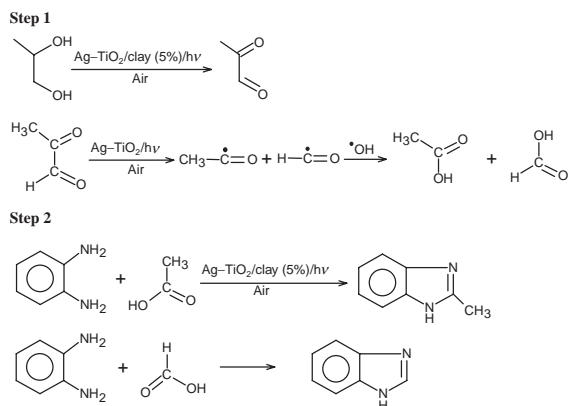
found to be more efficient photocatalyst for the production of 2MBZ and BZ. This photocatalytic reaction using TiO₂/clay (5%) composite catalyst was also carried out with PD and primary alcohols such as ethanol, propanol and butanol. The results are summarized in Table 2. It was observed that the reaction proceeded efficiently with anhydrous primary alcohols giving respective 2-alkylbenzimidazoles in good yield. Benzimidazole was not formed with primary alcohols. When air was replaced by nitrogen the reaction did not yield any product of our interest.

Based on the results we propose the following mechanism (Scheme 1). 1,2-Phenylenediamine being a basic reactant is adsorbed completely on the strong acidic clay and then propylene glycol undergoes oxidation to keto aldehyde at the oxidizing site of TiO₂. It is already established that alcohols can be easily oxidized on semiconductor surfaces to corresponding aldehyde or ketone.¹⁰ The keto aldehyde undergoes further oxidation forming acetic acid and formic acid. The acetic acid and formic acid generated in situ reacts with PD to give 2MBZ and BZ. Thermal reactions for the formation of 2MBZ and BZ from PD and acetic acid and formic acid have been reported.¹¹ When the photocatalytic reaction between PD and PG was carried out in presence of TiO₂/zeolite the products formed were 2-methylquinoxaline and quinoxaline. As per the mechanism proposed,⁹ first 2-methylquinoxaline was formed by the cyclization of keto aldehyde with PD then the 2-methylquinoxaline undergoes oxidative decarbox-

Table 2. Yield obtained after 15 h irradiation of UV-A light/solar light on photocyclization of PD and primary alcohols^a with TiO₂/clay (5%) catalyst

Reactants	Products/%	
	UV	Solar
PD + PG	2MBZ-62, BZ-30	2MBZ-60, BZ-30
PD + EtOH	2MBZ-35	2MBZ-16
PD + PrOH	2EtBZ-75	2EtBZ-60
PD + BuOH	2PrBZ-63	2PrBZ-48

^aCondition same as in Table 1.



Scheme 1. Proposed reaction mechanism for the formation of 2MBZ and BZ.

ylation in presence of $\text{TiO}_2/\text{zeolite}$ to give quinoxaline. But in presence of TiO_2/clay (5%) composite catalyst we found the simultaneous formation of 2MBZ and BZ. This is possible only by the cyclization of PD with acetic acid or formic acid. This reveals that in presence of TiO_2/clay , the keto aldehyde formed, undergoes further oxidation by TiO_2 to give acetic acid and formic acid.

The formation of acid intermediates with this catalyst was also confirmed by products obtained from PD and primary alcohols (Table 2). Ethanol, propanol, and butanol formed only 2-methyl-, 2-ethyl-, and 2-propylbenzimidazoles by cyclization of PD with the corresponding acids. Benzimidazole was not formed in these reactions because there was no chance of getting formic acid as in propylene glycol. Among the primary alcohols, the efficiency of cyclization is high with propanol, and low with ethanol. This is because of the presence of electron donor methyl group in propanol. The less efficiency of butanol when compared to propanol is due to the steric effect of bulky propyl group. The yields of 2-methylquinoxaline and quinoxaline in presence of $\text{TiO}_2/\text{zeolite}$ were only 22.5 and 12.6% respectively.⁹ But in presence of TiO_2/clay the photocyclization was highly efficient, giving 60% 2MBZ and 30% BZ.

The photocatalytic cyclization reaction of PD with PG was carried out with the composite clay catalysts prepared using TiO_2 (anatase), $\text{TiO}_2\text{-P25}$, and Ag-TiO_2 and the results are shown in Table 3. With UV light Ag/TiO_2 and $\text{TiO}_2\text{-P25}$ are equally efficient giving 92% yield in 8 h. But TiO_2 (anatase) gives only 90% yield at a longer irradiation time of 10 h. Under solar irradiation Ag/TiO_2 is more efficient showing 97% conversion in 8 h. The order of activity of these catalysts in solar light is Ag/TiO_2 (97%) > $\text{TiO}_2\text{-P25}$ (86%) > TiO_2 (anatase) (80%, 10 h).

The higher activity of Ag-TiO_2 catalyst in solar light has already been proved in the degradation of azo dyes.⁶ The Ag particles act as electron traps, enhancing the electron-hole separation and subsequent transfer of the trapped electron to the adsorbed O_2 .¹²

The formation of 2-alkylbenzimidazoles during the photocyclization of PD and PG/primary alcohols at ambient temperature with UV/solar light is reported over $\text{TiO}_2/\text{acidic clay}$ (5%) photocatalyst for the first time. A mechanism involving the cyclization of PD with the acid is proposed. Nano Ag-TiO_2

Table 3. Comparison of photocatalytic activities of TiO_2 and Ag-TiO_2 catalysts in UV and solar light

Conditions ^a	Irr. time /h	2MBZ/%		BZ/%	
		UV	Solar	UV	Solar
TiO_2/clay (5%)/air	10	60	46	30	34
$\text{Ag-TiO}_2/\text{clay}$ (5%)/air	8	59	67	33	30
$\text{TiO}_2\text{-P25}/\text{clay}$ (5%)/air	8	62	56	30	30

^aCondition same as in Table 1.

is found to be efficient than $\text{TiO}_2\text{-P25}$ and TiO_2 (anatase) for the synthesis of 2-alkylbenzimidazole under solar radiation and hence the use of Ag-TiO_2 makes this synthesis as green technological process. The photocyclization efficiency of $\text{TiO}_2/\text{acidic clay}$ is much more higher than the $\text{TiO}_2/\text{zeolite}$.

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- 8 All reactions were performed with mole ratio 1:2 of 1,2-phenylenediamine and propylene glycol in 25 mL of acetonitrile using 200 mg of $\text{Ag-TiO}_2/\text{acidic clay}$ (5%) catalyst in a cylindrical round-bottomed quartz photoreactor of 50 mL capacity under aerated conditions (8.1 mL s^{-1}). The loss of solvent due to evaporation was compensated periodically. The reaction mixture was irradiated with 365 nm light (8 lamps of 8 W each) for 8 h. After irradiation, the samples were subjected to GC analysis for the determination of the yield. The same experimental setup was used for solar light. The separation of products was performed by column chromatography on a silica-gel column by eluting with a co-solvent of dichloromethane and methanol (4:1 v/v). The structures of the products were confirmed with $^1\text{H NMR}$, $^{13}\text{C NMR}$, and GC-Mass spectra (ref. 13).
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