

Research Article

Chemical Functionalization of Cellulose Fabric for the Incorporation of Photosensitive Dyes: Optimization of Functionalization for the Grafting of Rose Bengal

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Abstract

This study presents an optimized method for grafting the photosensitive dye Rose Bengal onto cellulosic fabric to develop functional textile materials with photoactive properties. The two-step approach involved tosylation of hydroxyl groups followed by nucleophilic azidation under varying conditions of temperature (40-80 °C), reaction time (20-60h), sodium azide concentration (5-30 equivalents), and solvent volume (1.5-4mL of DMF). Optimal azidation conditions-20 equivalents of NaN₃ in 3mL DMF at 60 °C for 40h-yielded an azide-functionalized cellulose (Cell-AZO) with 8.75% nitrogen content and a degree of substitution (DS) of 0.4, indicating functionalization at approximately four C6-OH groups per ten glucose units. The Cell-AZO substrate was subsequently grafted with a propargyl-esterified derivative of Rose Bengal through copper-catalyzed azide-alkyne cycloaddition (CuAAC), producing a photoreactive cellulose fabric (Cell-RBe). Spectroscopic characterization using FT-IR showed the appearance of ester (1738cm⁻¹) and aromatic (1546cm⁻¹) bands, confirming the presence of the dye, while the disappearance of the azide signal (~2100cm⁻¹) validated reaction completion. XPS analyses revealed the presence of Cl and I from Rose Bengal and triazole N1s binding energy peaks (400.3 and 402.0eV), confirming covalent attachment. The functionalized fabric preserved structural integrity while introducing chromophoric groups, demonstrating the viability of this chemical strategy for producing smart textiles. The method's scalability and compatibility with aqueous processing open perspectives for sustainable applications in antimicrobial textiles, photocatalytic supports, and optoelectronic devices.

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Keywords

Cellulosic Fabric, Grafting, Azidation, Click Reaction, Rose Bengal, Characterization

1. Introduction

Advances in materials science, particularly in functional textiles, have prompted the exploration of new chemical modification strategies to enhance the properties of natural materials like cellulose [1]. As the most abundant natural organic polymer, cellulose is renewable and biodegradable, making it a key focus for sustainable material development [2]. However, inherent limitations such as hydrophilicity, low chemical resistance, and limited reactivity toward certain functional molecules restrict its broader application. This has led to increased interest in targeted chemical modifications to improve its functionality [3]. In particular, chemical functionalization of cellulose has gained attention for integrating advanced features such as photosensitivity [4]. Functionalization enables the introduction of reactive groups or external molecules, paving the way for smart textiles and novel applications [5, 6]. Among these, the grafting of Rose Bengal (a well-known photosensitizer used in biomedical and textile applications) has emerged as a promising strategy [7]. Rose Bengal generates reactive oxygen species under light, making it suitable for phototherapy, textile disinfection, and optical sensors [8, 9].

However, directly applying Rose Bengal onto cellulose poses technical challenges related to bond durability, wash resistance, uniform distribution, and environmental concerns associated with conventional processes [10]. These issues stem largely from the chemical incompatibility between the dye and the substrate, the stability of grafted bonds, and the need to preserve the fabric's mechanical and aesthetic integrity [11, 12]. The hydroxyl-rich structure of cellulose often requires pre-activation or coupling strategies to enable stable grafting [13].

Recent studies have demonstrated that activating cellulose hydroxyl groups with agents like maleic anhydride significantly enhances dye anchoring [14, 15]. The use of mild catalysts (such as weak acids, enzymes, or organometallics) can preserve fabric structure while ensuring stable functionalization [16]. Additionally, co-solvents and biphasic systems have been explored to improve Rose Bengal's solubility, distribution, and reactivity on textile surfaces. This study aims to efficiently graft esterified Rose Bengal onto preactivated cellulose fabrics (Cell-RBe) by optimizing reaction conditions for effective functionalization. The resulting materials are characterized for photoactivity, mechanical integrity, and spectral behavior using FTIR, UV-Vis, electron microscopy, and thermogravimetric analysis. This work contributes to sustainable innovation in smart textiles for biomedical, optoelectronic, and environmental applications.

2. Experimental

2.1. Materials

All commercial solvents and reagents were used as received from Sigma-Aldrich, Fischer Scientific, and Alfa Aesar. Primary white tufting cellulose fabric ($\sim 100\text{g/m}^2$) served as the cellulose matrix. FTIR spectra were recorded using a Bruker Tensor 27 spectrometer with ATR mode. X-ray photoelectron spectroscopy (XPS) was performed on a Thermo Fisher K-ALPHA system with a monochromatic Al K α source ($h\nu = 1486.6\text{eV}$, $200\mu\text{m}$ spot). Chamber pressure was maintained at 10^{-7}Pa . Survey spectra (0-1150eV) were acquired at 200eV pass energy, and high-resolution spectra at 40eV. Charge neutralization was applied to all insulating samples, and data were processed using Thermo Fisher AVANTAGE software. Elemental analyses were conducted on a Thermo Fisher Flash 2000 CHNS analyzer.

2.2. Methods

2.2.1. Pretreatment Procedure of Cellulose Fabric (Cell)

Five pieces of primary white tufting cellulose fabric (approx. 750mg) were dispersed in 250mL of freshly prepared aqueous NaOH solution (10% w/w). The mixture was stirred for 24h on an orbital shaker. The cellulose fabric samples were washed six times with 50mL of ethanol and stored in ethanol.

2.2.2. Preparation of Tosylated Cellulose Fabric (Cell-OTs)

A piece of cellulose fabric (145mg, 0.81 mmol) was immersed in pyridine (10mL) and treated with p-toluenesulfonyl chloride (464mg, 2.44 mmol). The mixture was stirred for 20 h at 40 °C on an orbital shaker. The resulting Cell-OTs material was sonicated three times with 20mL of DMF and stored in DMF for the next step.

2.2.3. Preparation of Sodium Azide-Grafted Cellulose Fabric (Cell-AZo)

An isolated, non-dried piece of tosylated cellulose fabric (Cell-OTs, 0.81 mmol of glucose units) was immersed in DMF (10mL) and treated with NaN_3 (526mg, 8.10 mmol). The resulting mixture was stirred for 40 h at 60 °C on an orbital shaker. The Cell-AZo material was sequentially sonicated with 20mL each of H_2O , CH_3COCH_3 , EtOH, and

CH_2Cl_2 , then vacuum-dried.

2.2.4. Preparation of Esterified Rose Bengal-Grafted Cellulose Fabric (Cell-RBe)

- 1) Synthesis of Esterified Rose Bengal (Rose Bengal-5-yl propargyl ester)

To 10mL of anhydrous DMF, 1g of Rose Bengal (1 mol) was added, and the mixture stirred for 4 h at 80 °C in a water bath. Then, 300 μL of propargyl bromide (80% in toluene) at 27 °C was added to this Rose Bengal solution. After stirring the suspension for 30 min, the Rose Bengal derivative was purified on silica gel (SiO_2) using DCM/MeOH (85:15 v/v) as eluent.

- 2) Click reaction between esterified Rose Bengal (Rose Bengal-5-yl propargyl ester) and azide-grafted cellulose fabric (Cell-AZo)

Rose Bengal-5-yl propargyl ester ($\text{C}_{23}\text{H}_{54}\text{Cl}_4\text{I}_4\text{NaO}_5$, 6 eq, 496mg) and solvent (THF/water: 3/1mL) were added to the azide-functionalized cellulose fabric (Cell-AZo) in the presence of 10% anhydrous copper sulfate (CuSO_4 , 1.3mg) and sodium ascorbate ($\text{C}_6\text{H}_7\text{NaO}_6$, 1 eq, 16mg). The mixture was heated at 80 °C for 24 h with stirring on an orbital shaker. The functionalized fabric (Cell-RBe) was then washed by sonication successively with 20mL of the following: (H_2O + 10% EDTA), $\text{C}_3\text{H}_6\text{O}$, CH_2Cl_2 , and vacuum-dried for elemental analysis, FTIR, and XPS.

3. Results and Discussion

3.1. Preparation of Tosylated Cellulose Fabric (Cell-OTs)

Chemical modification of raw cellulose fabric requires a pre-activation step to enhance the reactivity of hydroxyl groups, which are otherwise chemically inert. This step involves partial disruption of the hydrogen bonding network, opening the most ordered polymer regions to chemical reaction, through a process similar to mercerization. In practice, fabric sheets were mercerized in 1 M aqueous NaOH for 24 hours at room temperature, then washed with ethanol until neutral pH. The activated sheets can be stored for several days in ethanol under inert atmosphere before functionalization [17, 18]. Tosylation was then performed to activate the alcohol groups as good leaving groups for grafting. The reaction used an equimolar amount of p-toluenesulfonyl chloride in pyridine on mercerized fabric (Cell) for 20 hours at 40 °C, yielding the tosylated derivative (Cell-OTs) with a degree of substitution (DS) of 0.5, meaning one out of two glucose units was functionalized (Figure 1). Successive ethanol washes removed pyridine and excess reagents. Tosylation is assumed to occur mainly at the highly reactive C6 position of the anhydroglucose unit [3, 19].

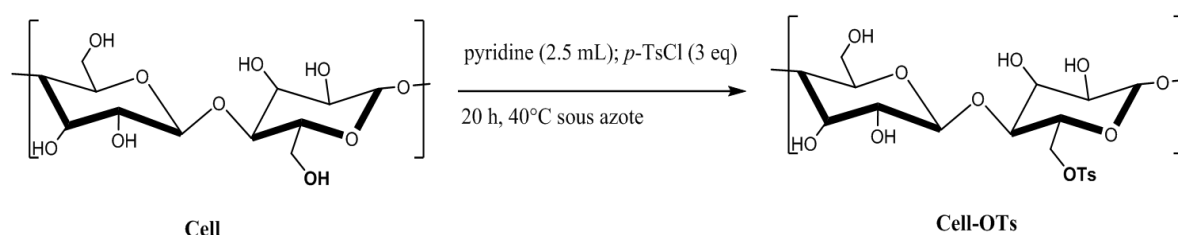
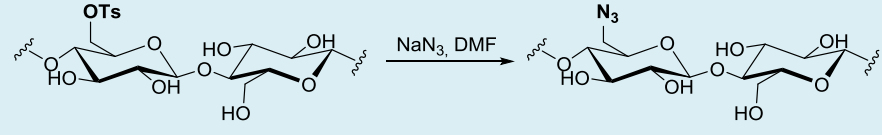


Figure 1. Preparation of Cell-OTs.

3.2. Preparation of Sodium Azide-Grafted Cellulosic Fabric (Cell-AZo)

Table 1. Optimization of the synthesis conditions for Cell-AZo material.

						
Entry	NaN_3 (Eq)	DMF (mL)	Temperature (°C)	Time (h)	Nitrogen grafting rate (%N)	Cell-AZo
1	5	1.5	40	40	2,47	Cell-AZo
2	5	1.5	60	40	2,72	Cell-AZo
3 ^b	5	1.5	80	40	2,94	Cell-AZo ^b
4	5	2	60	40	3,58	Cell-AZo

Entry	NaN ₃ (Eq)	DMF (mL)	Temperature (°C)	Time (h)	Nitrogen grafting rate (%N)	Cell-AZo
5	5	2.5	60	40	3,66	Cell-AZo
6	5	3	60	40	4,05	Cell-AZo
7	5	3.5	60	40	4,29	Cell-AZo
8	5	4	60	40	4,34	Cell-AZo
9	10	2	60	40	5,49	Cell-AZo
10	10	2.5	60	40	5,72	Cell-AZo
11	10	3	60	40	6,87	Cell-AZo
12	20	2.5	60	40	7,94	Cell-AZo
13 ^a	20	3	60	40	8,75	Cell-AZo ^a
14	20	3.5	60	40	8,98	Cell-AZo
15	20	4	60	40	9,07	Cell-AZo
16	30	2.5	60	40	9,11	Cell-AZo
17	30	3	60	40	9,24	Cell-AZo
18	30	3.5	60	40	9,35	Cell-AZo
19 ^b	20	3	60	60	9,72	Cell-AZo ^b
20	20	3	60	20	6,01	Cell-AZo
21 ^c	0	3	60	40	0,00	Cell-AZo ^c

a: Optimal reaction conditions: Cell-OTs (0.81 mmol) and NaN₃ (20 eq) were stirred on an orbital shaker in DMF (3mL) at 60 °C for 40 hours.
 b: Cell-AZob was damaged. c: Cell-AZoc is the blank from the experiment. Note: The nitrogen grafting rate (%N) was calculated by elemental analysis as the average of three experiments.

Cell-AZo was prepared in two steps from mercerized virgin cellulosic fabric. The process involved selective activation of C6 hydroxyl groups by tosylation, followed by nucleophilic displacement with sodium azide (NaN₃) via a classical SN₂ substitution (Table 1). Grafting efficiency depends on several intrinsic and extrinsic parameters related to the modified cellulose structure. Among these, temperature, reaction time, and solvent nature play key roles, influencing grafting kinetics, nitrogen incorporation, and the material's final physico-chemical properties [6]. Temperature control helps optimize substitution rates while limiting matrix degradation. Reaction time affects the homogeneity of azide group distribution; excessive durations may lead to side reactions or partial degradation [20]. Dimethylformamide (DMF) was used as solvent due to its ability to solubilize NaN₃ and promote diffusion into amorphous cellulose regions, enhancing reactivity [21]. Grafting azide groups onto the tosylated fabric allowed covalent anchoring of nitrogen functionalities, forming the Cell-AZo compound, which carries azide groups suitable for further

“click chemistry” reactions such as azide-alkyne cycloaddition. Notably, a magnetic stir bar was avoided, as it caused mechanical degradation of the fabric by abrasion. The degree of substitution (DS) of Cell-AZo, based on elemental analysis, was 0.4, indicating ~40% of anhydroglucose units were functionalized, mainly at the C6 position [22].

3.3. Influence of Temperature on Nitrogen Content

Reaction temperature is a key parameter in the grafting process of azide onto cellulose. Figure 2 shows that at a moderate temperature of 60 °C, the nucleophilic substitution reaction is more efficient, leading to a significant increase in the nitrogen content incorporated into the cellulosic structure. This can be attributed to the acceleration of molecular collisions and improved diffusion of sodium azide into the fibrous matrix at these temperatures [6, 23]. However, when the temperature reaches the threshold of 80 °C, thermal degrada-

tion phenomena of cellulose begin to occur, resulting in a decrease in grafting efficiency. At such high temperatures, the glycosidic bonds within the cellulose begin to break, causing a loss of the fabric's structural integrity. This observation aligns with Zervos and Alexopoulou (2015), who reported significant thermal degradation above 75-80 °C. While higher temperatures (>70 °C) can accelerate reactions, they also increase side reactions and structural defects [24]. Recent studies confirm that a moderate temperature range (60-65 °C) over extended reaction times offers a good compromise between yield and fabric stability [25].

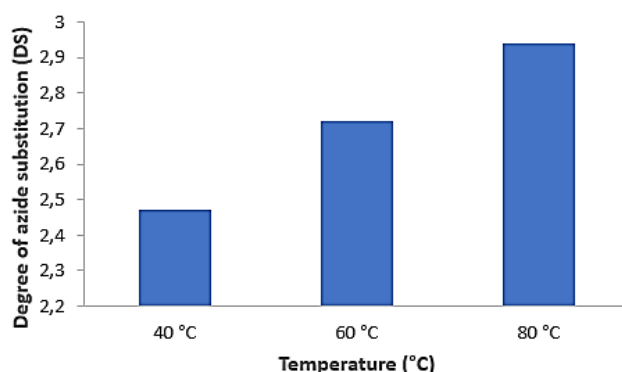


Figure 2. Temperature profile of azide grafting rate on Cell-AZo (DMF volume = 1.5mL; time = 40h; NaN_3 amount = 5 eq).

3.4. Influence of Reaction Time on Nitrogen Content

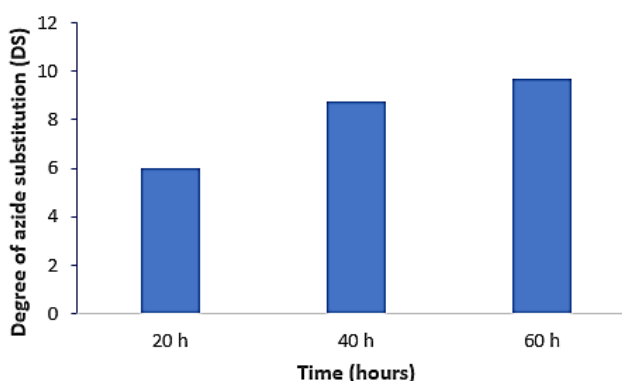


Figure 3. Time profile of azide grafting rate onto Cell-AZo (DMF volume = 3mL; temperature = 60 °C; NaN_3 amount = 20 eq).

Increasing the reaction time generally promotes better diffusion of sodium azide within the cellulose matrix, leading to greater incorporation of the azide group. As shown in Figure 3, extending the reaction time up to 40 hours results in a significant increase in grafted nitrogen content, due to the initial availability of numerous reactive hydroxyl sites on the cellulose [26]. However, beyond a certain time threshold,

particularly at 60 hours, undesirable effects begin to emerge. The sharp rise in nitrogen content (up to 9.72%) may indicate not only intense grafting but also non-specific side reactions or even partial degradation of the cellulose substrate [27]. Recent literature indicates that the grafting rate tends to stabilize over time due to saturation of reactive sites [19]. Excessive durations can lead to thermal or hydrolytic degradation of the azide groups or the cellulose backbone [28]. Proper kinetic control is essential to limit by-products and preserve mechanical properties, with optimal reaction times often ranging from 12 to 36 hours depending on the conditions [29, 30].

3.5. Influence of Reagent Concentration on Nitrogen Content

The efficiency of azide grafting onto cellulose is closely linked to the sodium azide (NaN_3) concentration in the reaction medium. As shown in Figure 4, a moderate increase generally improves nitrogen grafting, enhancing the material's functional properties, particularly its potential as a reactive platform for further modifications [30]. However, excessively high NaN_3 concentrations can lead to saturation of hydroxyl sites, disruption of interchain hydrogen bonds essential for fabric cohesion, and partial solubilization in polar solvents like DMF or THF [31]. The loss of physical integrity in highly grafted fabrics is often due to an imbalance between reactivity and structural stability, typically observed at degrees of substitution (DS) above 0.5, compromising the material's functionality [30]. Sodium azide's high reactivity stems from the azide group ($-\text{N}_3$), a nucleophile in substitution reactions on tosylated sites ($-\text{OTs}$) in the fabric [32]. Grafting efficiency also depends on NaN_3 stability, which decreases in moist environments [33]. Thus, a careful optimization led to selecting 20 equivalents as a good compromise between high grafting yield and preserved mechanical properties.

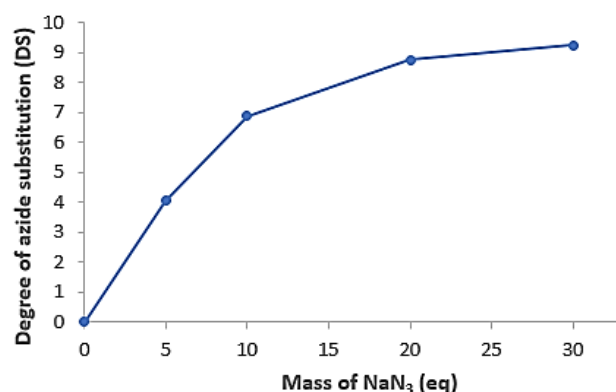


Figure 4. Effect of NaN_3 Mass on azide grafting rate onto Cell-AZo (DMF volume = 3mL; temperature = 60 °C; time = 40 h).

3.6. Influence of Solvent Quantity on Nitrogen Content

The concentration of the organic solvent, particularly dimethylformamide (DMF), plays a key role in the efficiency of azide group ($-N_3$) grafting onto cellulose. A suitable DMF amount ensures good sodium azide solubility and homogeneous distribution in the reaction medium, as shown in Figure 5. When the quantity of DMF is too low (1.5 mL), sodium azide does not dissolve sufficiently, resulting in reduced system reactivity [30]. Conversely, an excessive amount of

DMF (4 mL) leads to a significant dilution of the solution, decreasing the probability of contact between the reactants and the available hydroxyl sites on the cellulose fabric [31]. The optimal DMF volume, found to be 3 mL in the studied system, achieves a balance between maximal sodium azide solubility and the reactivity of its azide groups ($-N_3$), while maintaining the structural integrity of the cellulose fabric. This optimization improves both grafting yield and material functionality [32]. DMF's stability in slightly basic media makes it well-suited for such modifications [33].

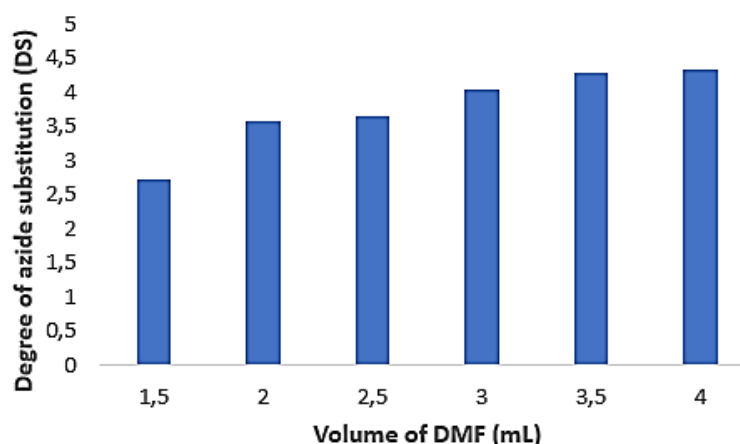


Figure 5. Profile of DMF volume on the azide grafting rate on Cell-AZo (NaN_3 mass = 5 eq; temperature = 60 °C; time = 40h).

3.7. Functionalization of Modified Cellulose Fabric with Rose Bengal (Cell-RBe)

The functionalization of cellulose fabric with Rose Bengal relies on a "click chemistry" reaction, specifically a copper-catalyzed azide-alkyne 1,3-dipolar cycloaddition (CuAAC). This highly regioselective and efficient reaction forms stable triazole linkages between azide-modified cellulose (Cell-AZo) and Rose Bengal bearing a terminal alkyne group.

The mechanism involves in situ reduction of Cu(II) by sodium ascorbate to generate Cu(I), the active catalyst. This step

occurs in a refluxing aqueous/THF medium, ensuring reactant solubility and mild conditions compatible with sensitive substrates [34]. Triazole linkages provide good stability and act as rigid bridges between cellulose and Rose Bengal. Grafting efficiency depends on the density of azide groups [35]. CuAAC is well suited for such systems due to its solvent tolerance, fast kinetics, and high yield. This functionalization is particularly compatible with cellulose, thanks to its hydroxyl-rich structure and aqueous processing conditions [36]. Figure 6 shows the overall reaction: Cell-AZo fabric reacts with an alkyne-Rose Bengal in the presence of $CuSO_4$ /sodium ascorbate in THF/ H_2O , forming the photoreactive fabric Cell-RBe.

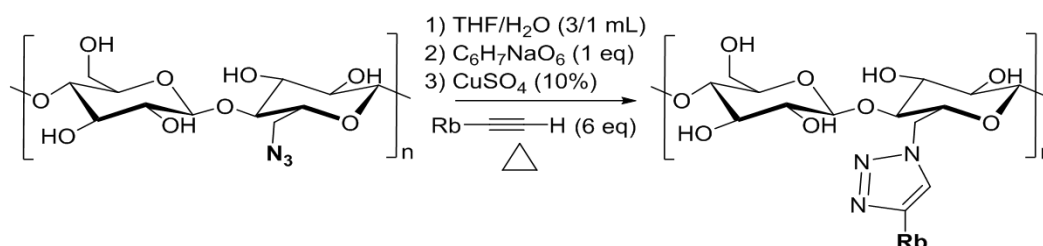


Figure 6. Preparation of Cell-RBe.

3.8. Characterization

1) Characterization by Fourier Transform Infrared Spectroscopy (FT-IR)

The structural characterization of the pristine cellulose fabric (Cell), azidated cellulose (Cell-AZo), and Rose Bengal-functionalized cellulose (Cell-RBe) was performed by Fourier Transform Infrared Spectroscopy (FT-IR), a powerful technique for monitoring chemical modifications at the molecular level (Figure 7). The FT-IR spectra reveal the presence of characteristic bands of the cellulose backbone in all three sample types. The two broad bands around 3400cm^{-1} ($\nu(\text{O-H})$) and 1100cm^{-1} ($\nu(\text{C-O-C})$) are typical of hydroxyl bonds and ether bridges of cellulose. The stretching vibration of methyl and methylene groups also appears around 2900cm^{-1} ($\nu(\text{C-H})$). The band at 1641cm^{-1} corresponds to the bending mode $\delta(\text{H-O-H})$ of physically adsorbed water on the cellulose surface, as well documented in the literature [37]. After the azidation reaction, the appearance of a distinct band near

2100cm^{-1} confirms the introduction of azide groups ($-\text{N}_3$) via nucleophilic substitution on the previously activated sites, validating the success of the initial grafting [38]. In the spectrum of the Cell-RBe material, this 2100cm^{-1} band becomes almost undetectable, suggesting near-complete conversion of the azide groups during the CuAAC cycloaddition. The emergence of new characteristic bands of Rose Bengal confirms this functionalization, notably the bands at 1330 , 1450 , and 1546cm^{-1} corresponding to aromatic $\nu(\text{C}=\text{C})$ stretching vibrations of the chromophore, as well as the band at 1738cm^{-1} attributed to the $\nu(\text{C}=\text{O})$ stretching vibration of the ester function, indicating that the dye grafting onto the cellulose matrix occurred via a triazole linkage [39, 40]. These results are consistent with recent studies using FT-IR to monitor cellulose functionalization, where the appearance of characteristic bands of carbonyl, aromatic, and nitrogenous groups confirms the introduction of photoactive functions [41].

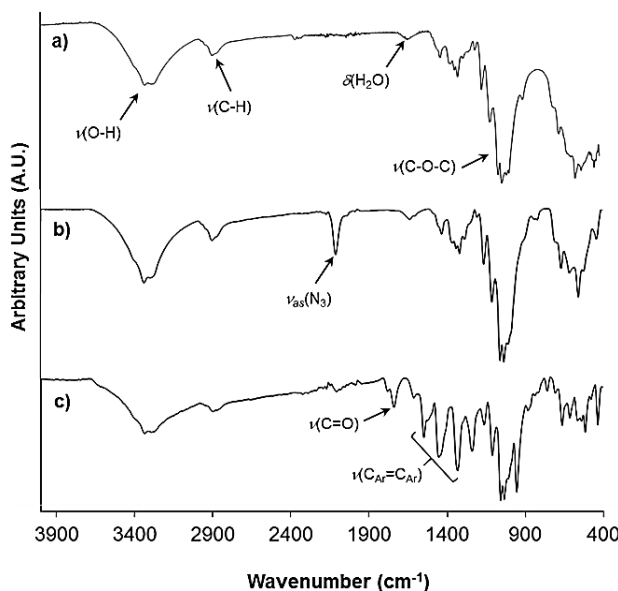


Figure 7. FT-IR spectra of (a) Cell, (b) Cell-AZo, and (c) Cell-RBe.

2) Characterization by X-ray Photoelectron Spectroscopy (XPS)

The results obtained by Fourier Transform Infrared Spectroscopy (FT-IR) were corroborated by X-ray Photoelectron Spectroscopy (XPS), a key technique for examining the elemental composition and chemical state of functionalized surfaces at the nanometric scale (Figure 8). The full survey spectrum of the pristine cellulose fabric (Cell) shows the exclusive presence of carbon (C 1s) and oxygen (O 1s), the fundamental elements of the cellulose sugar backbone [42]. After azidation (Cell-AZo), a characteristic nitrogen band (N 1s) appears, with a peak around $404\text{--}405\text{eV}$, attributed to the electron-deficient nitrogen of the azide group ($-\text{N}_3$), confirming effective insertion via nucleophilic substitution [43].

The survey spectrum of the Cell-RBe sample reveals the appearance of two new elements: chlorine (Cl 2p) and iodine (I 3d), characteristic signatures of Rose Bengal, confirming the grafting of the dye onto the cellulose surface [39]. In the high-resolution C 1s spectrum of Cell-RBe, an increase in intensity at 285.0eV is observed, corresponding to the newly introduced C-C/C-H bonds from the aromatic rings of Rose Bengal. Other notable contributions appear at 286.5eV (C-O) and 288.1eV (C=O), confirming the presence of esters on the modified surface [38]. The high-resolution N 1s region spectrum of Cell-RBe shows two peaks at 400.3eV and 402.0eV , corresponding respectively to N-C (triazole) bonds and N=N or N-Ar bonds, suggesting complete conversion of azide groups into triazole heterocycles. The disappearance of the

peak at 404-405eV, associated with the azide, confirms the successful [3, 2] cycloaddition between the azide and the alkyne dye (Rose Bengal), typical of a click reaction (CuAAC) [44]. These results not only confirm the success of the covalent

grafting of Rose Bengal but also attest to the purity of the modified surface, a crucial condition for photodynamic or optoelectronic applications.

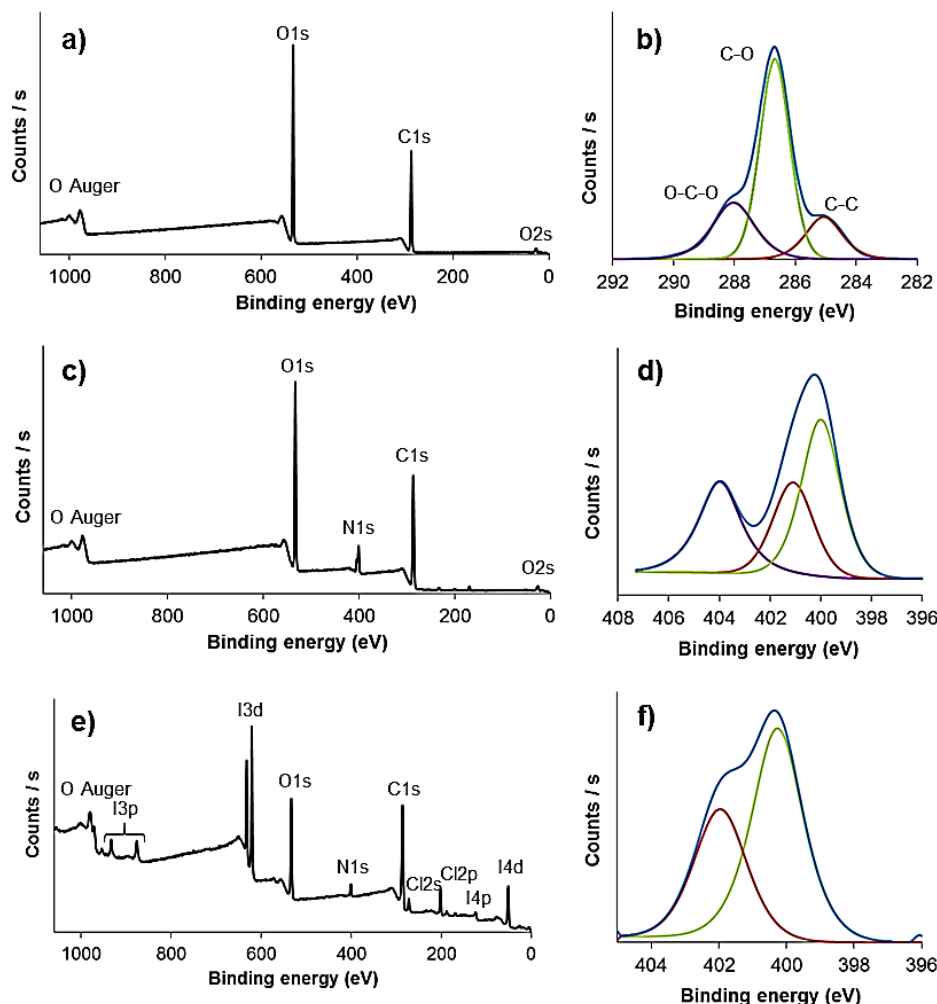


Figure 8. Survey spectra of (a) Cell, (c) Cell-AZo, and (e) Cell-RBe; High-resolution spectra of (b) C1s for Cell, (d) N1s for Cell-AZo, and (f) N1s for Cell-RBe.

4. Conclusion

This work successfully established a robust and optimized chemical pathway for the covalent functionalization of cellulose fabric with photosensitive Rose Bengal dye. Through a sequential process involving mercerization, tosylation, and azidation, a high degree of azide substitution (up to 8.75% nitrogen content and DS = 0.4) was achieved under optimal conditions (60 °C, 40 h, 3mL DMF, 20 equivalents of NaN_3). The azide-modified fabric (Cell-AZo) provided a highly reactive platform for subsequent click chemistry with propargyl-esterified Rose Bengal via Cu(I)-catalyzed azide-alkyne cycloaddition (CuAAC).

The successful grafting was confirmed by FT-IR, showing the disappearance of the azide band ($\sim 2100\text{cm}^{-1}$) and the

emergence of ester and aromatic signals characteristic of Rose Bengal (1738 , 1546 , and 1330cm^{-1}). XPS analysis further confirmed the introduction of Cl and I atoms and triazole bonds (N 1s at 400.3 and 402.0eV), demonstrating effective and stable covalent attachment of the dye to the cellulose matrix. These results validate the efficiency, selectivity, and chemical stability of the grafting strategy employed.

The modified fabric (Cell-RBe) retained its mechanical integrity despite undergoing multiple chemical transformations, highlighting the compatibility of the process with textile substrates. This functional material possesses promising features for light-activated applications such as antimicrobial textiles, environmental photocatalysis (e.g., degradation of pollutants under visible light), smart sensors, and

photodynamic therapeutic platforms. Furthermore, the use of aqueous-compatible and moderately reactive conditions supports the potential for eco-friendly scale-up in textile finishing or biomedical material production.

Future studies will focus on evaluating the photophysical behavior and reusability of the functionalized fabric under real-use conditions, assessing photostability, reactive oxygen species (ROS) generation efficiency, and wash resistance. Expanding this methodology to other dyes and biopolymer supports could broaden the scope of application in sustainable and multifunctional textile design.

Abbreviations

Cell	Cellulose Fabric
Cell-OTs	Tosylated Cellulose Fabric
Cell-AZO	Sodium Azide-Grafted Cellulose Fabric
Cell-RBe	Esterified Rose Bengal-Grafted Cellulose Fabric

Conflicts of Interest

The authors declare no conflicts of interest.

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