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SUSTAINABLE JUTE BLEACHING WITH SODIUM PERBORATE: COMPARATIVE STUDY ON EFFICIENCY AND ECO-IMPACT

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ABSTRACT

The textile industry substantially impacts environmental degradation owing to the widespread utilization of hydrogen peroxide (H_2O_2) as a bleaching agent, which produces detrimental byproducts and requires significant amounts of water and energy. This study explores the efficacy of sodium perborate ($NaBO_3 \cdot nH_2O$) as an eco-friendly alternative for bleaching jute fibers, emphasizing bleaching efficiency, fiber strength, and environmental impact. Experimental trials were conducted using sodium perborate at different concentrations and temperatures (60°C and 80°C), and results were compared with hydrogen peroxide treatment at 90°C. The sodium perborate-treated fibers demonstrated notably higher whiteness index (ΔCIE WI up to 71.60) than hydrogen peroxide-treated fibers (ΔCIE WI 4.2), while also maintaining superior tensile strength (up to 539.39 N compared to 234.31 N). Furthermore, wastewater from sodium perborate bleaching exhibited significantly lower total dissolved solids (222 ppm) and salinity (0.27 ppt) than peroxide effluent (4148.4 ppm and 4.2 ppt, respectively), indicating a much lower environmental burden. The controlled release of active oxygen from sodium perborate reduced fiber degradation and minimized chemical waste, confirming its efficiency under moderate alkaline conditions. In addition to its technical advantages, sodium perborate is more cost-effective and requires lower processing temperatures, thereby reducing the overall energy consumption. The findings suggest that sodium perborate is a sustainable and economically viable alternative for jute bleaching, offering enhanced fiber quality and reduced environmental footprint, and should be considered for industrial-scale implementation to support greener textile processing.

Keywords: *Green Bleaching, Sodium Perborate, Whiteness Index, Fibre Tensile Strength, Environmental Impact*

1. INTRODUCTION

Jute, frequently referred to as the "golden fiber," is a biodegradable, renewable, and environmentally sustainable natural fiber derived from Corchorus species primarily grown in Bangladesh, India, China, and Thailand. Jute, which is second only to cotton in terms of global importance, is utilized in textiles (carpet, upholstery, bags, and ropes), industrial applications (geotextiles, reinforcements, and composites), and eco-friendly packaging materials (Ahmed, 2021). Recent literature emphasizes that the global shift toward a circular bio-economy has renewed interest in jute as a strategic alternative to synthetic fibers (Suvam Nanda, 2025) (R. Karthikeyan, 2024)

The composition of jute fibers —primarily comprising cellulose (60–65%), hemicellulose (12%), and lignin (10–12%)— provides jute fibers with considerable tensile strength and hardness, yet also imparts a coarse texture and yellowish-brown color resulting from lignin and other chromatic metrics (Aziz, 2015) (Bahlool, 2020) (Islam M. A., 2011).

Its natural color restricts its use in cotton-grade, high-value fabrics, necessitating bleaching to enhance whiteness, softness, and color assimilation (Banerjee, 2016).

Traditional jute bleaching often involves the use of hydrogen peroxide (H_2O_2), sodium hypochlorite (NaClO), or chlorine-based compounds. Although these molecules are effective, they raise serious environmental concerns. Sodium hypochlorite and chlorine-containing compounds generate hazardous chlorinated byproducts, while hydrogen peroxide produces them only under stringent process regulation, accompanied by heavy water and energy consumption (Brosnan, 2001) (Bulut, 2013). Furthermore, the high salinity and total dissolved solids (TDS) in conventional peroxide effluent pose long-term risks to aquatic biodiversity and soil health (Anees Ahmad, 2024). These difficulties pose significant enquiries regarding sustainability and wastewater management within the textile industry.

Sodium perborate ($NaBO_3.nH_2O$) is a promising alternative. It is a highly stable, crystalline compound, which, in water, gradually produces hydrogen peroxide and active oxygen under mild alkaline conditions. This controlled release facilitates efficient bleaching, minimizes fiber damage, and its decomposition byproducts—borates, water, and oxygen—are comparatively benign to the environment (Chattopadhyay, 2010) (Choudhury, 2017).

Sodium perborate, in contrast, exhibits enhanced storage stability, and may lower energy requirements at decreased processing temperatures (Fatma, 2016). Recent comparative studies on mechanical pulp and other natural fibers have shown that perborate-based systems can significantly reduce energy consumption while maintaining fiber bonding properties (ATİLA GÜRHAN ÇELIK, 2020).

Previous comparison investigations suggested that the whiteness of sodium perborate can approximate that of hydrogen peroxide while maintaining superior fiber tensile strength, and less fibrillation (Islam M. H., 2016) (Islam M. A., 2011)

Furthermore, sodium perborate-treated fibers demonstrated enhanced dyeability and reduced surface morphological roughness compared to conventionally bleached fibers (Pan, 2003). Innovative applications of per-oxygen chemistry continue to demonstrate that such "green" bleaching agents are essential for the transition toward non-toxic textile processing (Kabir, 2024). These findings suggest its potential to balance performance with environmental accountability.

Despite these benefits, the industrial application of sodium perborate bleaching for jute has not gained widespread acceptance, and systematic studies evaluating its efficiency, environmental impact (Ahmed Z. Y., 2020) and economic viability are scarce. This study, therefore, investigates the bleaching of jute fiber using sodium perborate, with specific focus on whiteness index, fiber tensile strength, and environmental impact relative to traditional hydrogen peroxide bleaching. This study seeks to enhance the development of environmentally friendly bleaching techniques in the textile sector by identifying optimal process parameters and emphasizing their ecological benefits.

2. METHODOLOGY

2.1 Materials

Raw material is the material that are used for making the finished product or purpose to aiming the final result. For reaching the target goal that we have mentioned above, we are using raw jute fibre (Table1). Jute fibre is composed of Cellulose (64%), Hemicellulose (12%), Lignin (11%), Pectin & Waxes (Seki Y, 2022). The jute fibre has a coarser texture and natural brownish colour due to the presence of lignin and impurities, which makes bleaching essential for improving its appearance, softness and dyeability. Specification of jute fibre that we are used in our project are given below:

Table 1:Jute fiber & its specification

Jute Fibre	Specification
Origin	Bangladesh
Fineness	Micronaire value 9-13
Span Length	1.2- 4 meter
Tenacity	3.5 gm/den
Trash content	5%- 10%

2.1.1 Apparatus

1. pH meter
2. Beaker
3. Measuring Cylinder
4. Steel Pot
5. Pipette Filler
6. Digital Balance
7. Stirring Rod

Figure 1: Jute

Figure 2: pH

Figure 3: Beaker with solution

Figure 4: Measuring Cylinder

2.1.2 Chemical & Auxiliaries

There were different types of chemical and auxiliaries that has been used for both methods.

I. **Sodium Perborate:** It is a bleaching agent that has been used instead of Hydrogen peroxide. The main function of sodium perborate is to remove natural yellowness of raw jute fibre.

II. **Hydrogen Peroxide:** It is a bleaching agent that is used typically to remove the natural colour of jute fibre.

III. **Wetting Agent:** Wetting Agent lowers the surface tension of liquid so that treated chemical easily penetrate through the fibre.

IV. **Sequestering Agent:** It is the chemical compound that removes metal ion from the water.

V. **Peroxide Stabilizer:** This stabilizer is used to prevent rapid decomposition of hydrogen peroxide by inhibiting its breakdown into water and oxygen.

VI. **Detergent:** Detergent is a cleaning agent that removes dirt, dust, oil, grease from surface of fibre.

VII. **Soda (Na_2CO_3):** It is used to control the pH of treated solution so that effective treatment takes place.

2.2 Method

Two- step bleaching has been conducted for this experiment. In first step, for making the green bleached jute, sodium perborate is used instead of hydrogen peroxide. Ten sample of jute fibre is treated with Sodium perborate, and one sample is treated with Hydrogen peroxide. Total, eleven sample have been taken for this method.

By using the following recipe (Table 2), sample 1-5 have been bleached. These sample was treated with sodium perborate. For each sample, different concentrated solution of sodium perborate has been prepared.

Table 2: Bleaching Recipe for Jute Sample (1-5)

Chemical	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Sodium Perborate	7.69 gm/l	15.3 gm/l	23 gm/l	30.77 gm/l	61.54 gm/l
Wetting Agent	2 ml/l				
Detergent	2 gm/l				
Time × Temp	60 min × 60°C				
M: L	1: 10				

Calculation:

Material weight = 20 gm (each sample), Total Liquor= 20 × 10 = 200 ml

Sodium perborate = $\frac{7.69 \times 200}{1000}$ = 1.53gm (sample-1) pH- 9.3
= $\frac{15.3 \times 200}{1000}$ = 3.06 gm (sample-2) pH- 9.3
= $\frac{23 \times 200}{1000}$ = 4.6 gm (sample-3) pH- 9.49
= $\frac{33.77 \times 200}{1000}$ = 6.754 gm (sample-4) pH-9.6
= $\frac{61.54 \times 200}{1000}$ = 12.30 gm (sample-5) pH-9.5

Wetting agent = $\frac{2 \times 200}{1000}$ = 0.4 ml

Detergent = $\frac{2 \times 200}{1000}$ = 0.4 ml

Total water required = 200 - (0.4+0.4) = 199.92 ml

Now by using the following recipe (Table 3), the jute fibre sample (6-10) have been bleached. This time the only difference between the recipe of sample (1-5) and sample (6-10) is temperature. Temperature has been increased by 20°C than previous temperature. The reason for this increase is that the effectiveness of sodium perborate bleaching significantly improves at higher temperature, meaning it works best under warmer conditions. Above 60°C it releases active oxygen more readily at elevated temperature.

Table 3: Bleaching Recipe for Jute Sample (6-10)

Chemical	**Sample 6**	**Sample 7**	**Sample 8**	**Sample 9**	**Sample 10**
Sodium Perborate	7.69 gm/l	15.3 gm/l	23 gm/l	30.77 gm/l	61.54 gm/l
Wetting Agent	2 ml/l				
Detergent	2 gm/l				
Time × Temp	60 min × 80°C				
M: L	1: 10				

Calculation:

Material weight = 20 gm (each sample), Total liquor - 20 × 10 = 200 ml

Sodium perborate = $\frac{7.69 \times 200}{1000}$ = 1.53gm (sample-6) pH- 9.35
= $\frac{15.3 \times 200}{1000}$ = 3.06 gm (sample-7) pH- 9.4
= $\frac{23 \times 200}{1000}$ = 4.6 gm (sample-8) pH- 9.45
= $\frac{33.77 \times 200}{1000}$ = 6.754 gm (sample-9) pH-9.6
= $\frac{61.54 \times 200}{1000}$ = 12.30 gm (sample-10) pH-9.32

Wetting agent $= \frac{2\times200}{1000} = 0.4$ ml
Detergent $= \frac{2\times200}{1000} = 0.4$ ml
Total water required = 200 - (0.4+0.4) = 199.92 ml

To compare the sodium perborate bleaching with hydrogen peroxide bleaching one sample has been treated with hydrogen peroxide by using the following recipe.

Bleaching recipe for jute sample (using H_2O_2 agent):
Hydrogen peroxide-- 5 ml/l
Peroxide stabilizer--- 2 ml/l
Na_2CO_3---------------- 5 gm/l
Wetting agent-------- 1 ml/l
Sequestering agent-- 1 gm/l
Detergent------------- 2 ml/l
Time × Temp.--------- 40 min × 90°C
M: L------------------- 1: 10

Calculation:
Material weight = 20 gm
Total liquor = 20 × 10 = 200 ml
Hydrogen peroxide $= \frac{5\times200}{1000} = 1$ml
Stabilizer $= \frac{2\times200}{1000} = 0.4$ ml
Soda $= \frac{5\times200}{1000} = 1$ gm
Wetting Agent $= \frac{1\times200}{1000} = 0.2$ml
Sequestering agent $= \frac{1\times200}{1000} = 0.2$ gm
Detergent $= \frac{2\times200}{1000} = 0.4$ ml
Total water required = 200 - (1+0.4+0.2+0.4) = 198 ml

The concentrations of sodium perborate (ranging from 7.69 g/l to 61.54 g/l) were selected based on stoichiometric oxygen availability compared to conventional hydrogen peroxide bleach. Specifically, the lower bound was chosen to represent a mild treatment, while the higher concentrations were calculated to determine the 'saturation point' where bleaching efficiency (whiteness index) reaches its peak before significant fiber degradation occurs. This systematic range aligns with recent investigations into sustainable bast fiber processing (Kabir, 2024). Furthermore, high concentrations up to 61.54 g/l were utilized to evaluate the limits of jute's structural resilience against controlled oxygen release (Seki Y, 2022).

2.2.1 Working Procedure

Initially, water was added to a beaker according to the specified recipe. Chemicals and auxiliaries for each sample were accurately measured and dissolved in the water. The resulting solution was thoroughly mixed using a stirring rod and then transferred into a steel pot. Individual jute fibre samples were placed in the pot, and all pots were loaded into the machine. The bleaching process was carried out under controlled time and temperature conditions (Fig 5a,5b,5c). After completion, the samples were rinsed with normal water. The treated solution (wastewater) was collected for further analysis. Finally, the bleached samples were dried using a hand dryer and stored in zipper bags for subsequent physical testing.

Machine Specification:

Machine Name	IR DYER
Speed	5-60 rpm clockwise

Brand	Labtech
Origin	Taiwan
Capacity	12 pots

2.2.2 Mechanism of Sodium perborate in Jute Bleaching

When dissolved in water, sodium perborate generates hydrogen peroxide and peracetic acid, which react with chromophores (color-causing molecules) in jute fibers.

It facilitates the oxidation and removal of lignin, hemicellulose, and other impurities, enhancing fibre whiteness and purity.

The process is effective under moderate pH (8–10) and temperature conditions, reducing overall chemical and energy requirements.

2.2.3 Reaction occurs in Sodium perborate Bleaching

The bleaching action of sodium perborate ($NaBO_3 \cdot nH_2O$) is primarily due to its ability to release hydrogen peroxide (H_2O_2) in aqueous solutions, which then generates reactive oxygen species that break down colored compounds in jute fibers. The reaction sequence can be outlined as follows:

1. Dissociation of sodium perborate in water

Sodium perborate hydrolyses in water to release hydrogen peroxide:

$$NaBO_3.nH_2O \rightarrow Na^+ + BO_3^- + H_2O_2$$

2. Decomposition of hydrogen peroxide

$$H_2O_2 \rightleftharpoons HOO^- + H^+$$

$$H_2O_2 \rightarrow 2OH$$

3. Oxidation of Colored Impurities in Jute

The per hydroxyl anion attacks chromophores (color centers) in lignin and other natural impurities, breaking conjugated double bonds and degrading unwanted pigments.

The reaction results in decolorization and removal of yellowish-brown components from jute.

2.3 Bleaching Curve

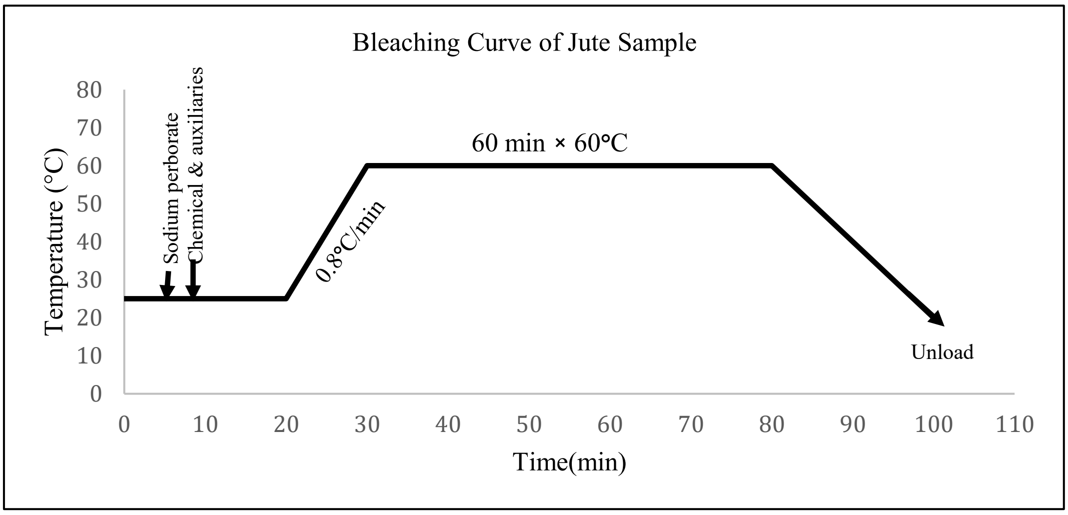

Figure 5(a): Bleaching Curve of Jute sample (1-5)

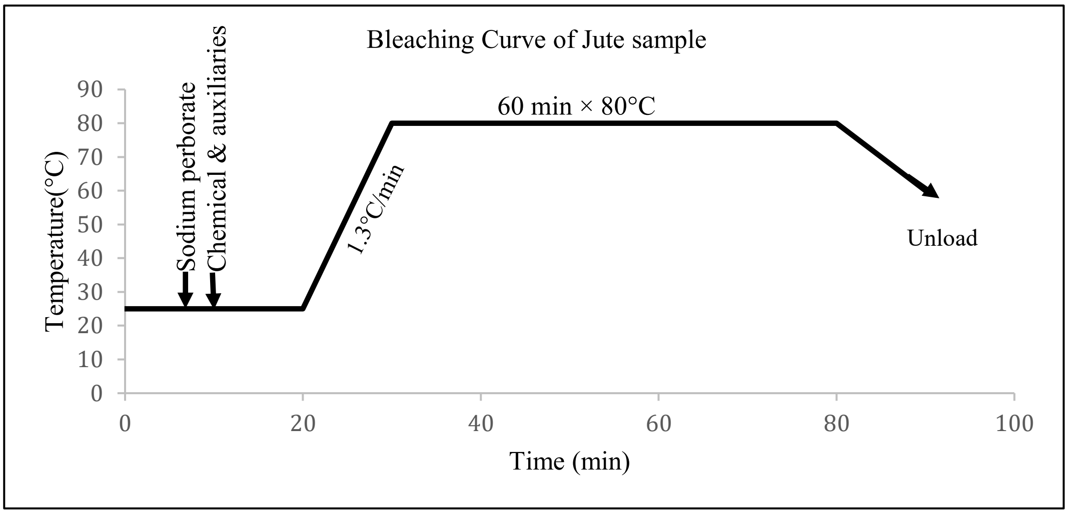

Figure 5(b): Bleaching curve of Jute sample (6-10)

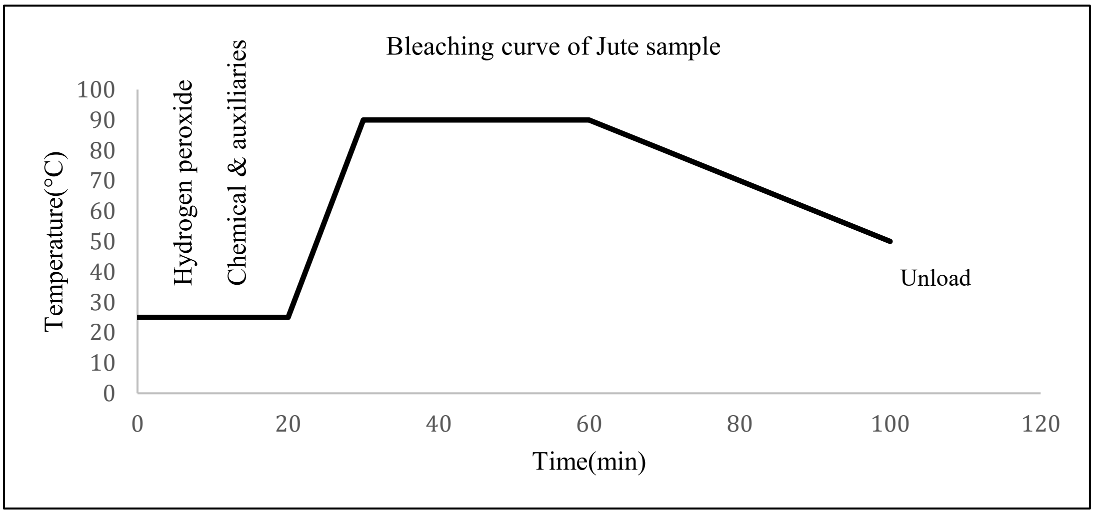

Figure 5(c): Bleaching Curve of Jute sample (11- H_2O_2 Agent)

The bleaching curves in Figure 5 demonstrate that sodium perborate operates at significantly lower peak temperatures (60°C–80°C) than hydrogen peroxide (90°C), representing a 10–30°C reduction that saves substantial energy and prevents thermal degradation of the jute. The gradual heating rates of 0.8°C/min and 1.3°C/min for perborate facilitate a controlled, phased release of active oxygen, allowing for deeper fiber penetration without the aggressive oxidation caused by rapid peroxide decomposition.

2.4 Testing Equipment:

I. **UTM Machine:** UTM mean Universal Testing Machine. This machine is used for testing the tensile strength of bleached jute fiber.
II. **TDS & Salinity Meter:** This machine used for measuring the waste (TDS and Salinity) of the treated solution after completing the bleaching.
III. **Spectrophotometer:** It is used for measuring the whiteness of the bleached Jute fiber.

Figure 6: UTM machine

Figure 7: TDS & Salinity meter

Figure 8: Spectrophotometer

3. RESULTS & DISCUSSION

3.1 Determination of Maximum Fore

The tensile properties of the jute fiber were evaluated using the grab test method in accordance with EN ISO 13934, version:2 (modified). This test measures the maximum force (in Newtons) required to break the fabric under controlled conditions. The test was conducted in the warp direction, with a jaw separation of 50.00 mm, Load cell 5000 N. (Islam M. H., 2016) (Seki Y, 2022)

Sample	Bleaching Agent	Mean Maximum Force (N)
1	Sodium Perborate	539.39
2	Sodium Perborate	371.14
3	Sodium Perborate	342.56
4	Sodium Perborate	233.10
5	Sodium Perborate	292.25
6	Sodium Perborate	467.19
7	Sodium Perborate	406.59
8	Sodium Perborate	360.16
9	Sodium Perborate	274.63
10	Sodium Perborate	264.64
11	Hydrogen Peroxide	234.31

3.1.1 Discussion

Figure 9 demonstrates that sodium perborate significantly improves fiber strength retention compared to conventional hydrogen peroxide. Sample 1 achieved a maximum force of 539.39 N, whereas the hydrogen peroxide sample (Sample 11) recorded only 234.31 N, indicating that the perborate treatment preserves over 130% more of the jute's original structural integrity. This occurs because the milder reaction conditions (60°C–80°C) and controlled oxygen release of sodium perborate prevent the formation of "oxy-cellulose," a common degradation product of high-temperature peroxide bleaching that weakens the cellulose molecular chains. By maintaining a higher tensile strength, sodium perborate-treated jute remains more durable for industrial textile applications, directly supporting the sustainable goal of extending the lifecycle of natural fiber products. (Brosnan, 2001); (Choudhury, 2017) (Islam M. H., 2016); (Seki Y, 2022)

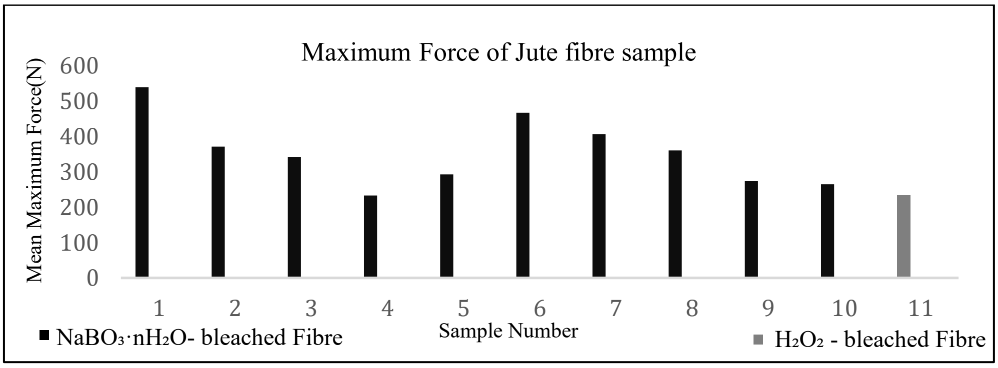

Figure 9: Comparison of Maximum forces

3.2 Salinity

Salinity refers to the concentration of dissolved salts in water, typically measured in parts per thousand (ppt). It is an important measure of water quality because it influences the suitability of water for a wide range of uses, including drinking water, agriculture, and industry. High salinity levels can have negative consequences for ecosystems, soil health, and infrastructure, making monitoring and management of salinity in water resources essential. (Banerjee, 2016) (Seki Y, 2022)
The salinity levels for the samples are presented below. The first ten samples were treated with sodium perborate, while the 11th sample was treated with hydrogen peroxide and its salinity level is 4.2 ppt.

Table 4: Salinity of Sodium Perborate treated sample (ppt)

Sample No.	Salinity	Sample No.	Salinity
1	0.27	6	2.8
2	4.5	7	4.6
3	5.9	8	6.7
4	8.0	9	8.7
5	14.0	10	14.9

3.2.1 Discussion

Table 4 shows the salinity values (0.27–14.9 ppt) indicate an eco-friendlier transition when optimized at lower concentrations. While the hydrogen peroxide sample (Sample 11) resulted in a salinity of 4.2 ppt, sodium perborate achieved superior whiteness at lower concentrations (Sample 1 and Sample 6) with salinity levels as low as 0.27 to 2.8 ppt. This demonstrates that sodium perborate can provide effective bleaching while maintaining freshwater-like conditions that are significantly less harmful to aquatic biodiversity than the brackish levels required by peroxide methods (Seki Y, 2022) (Banerjee, 2016). Furthermore, because sodium perborate functions effectively at 60°C, it minimizes the "thermal salinity effect"- where high- temperature discharge accelerates the concentration of dissolved minerals, thereby reducing the overall ecological footprint on local water resources (Anees Ahmad, 2024)

3.3 Total Dissolved Solid

The Total Dissolved Solids (TDS) values for the samples are presented in Table 5. TDS is a measure of the combined content of inorganic and organic substances dissolved in water, and it is expressed in parts per million (ppm) (Seki Y, 2022). Hydrogen peroxide treated 11th sample showed 4148.4 ppm TDS.

Table 5: TDS of Sodium Perborate treated sample (ppm)

Sample No.	TDS (ppm)	Sample No.	TDS (ppm)
1	222	6	2853.6
2	4414.8	7	4513.2
3	5683.8	8	6396
4	7470	9	8064
5	12570	10	13272

3.3.1 Discussion

According to the table 5, Sample 1 showed the lowest TDS, indicating minimal dissolved solids and relatively clean water. Samples 2, 3, 6, 7, and 8 exhibited moderate TDS, typical of natural or industrial sources influenced by dissolved minerals or organic matter. Samples 4, 5, 9, and 10 had notably higher TDS, suggesting industrial contamination. Among all, Samples 1 and 6 demonstrated lower TDS than Sample 11, indicating better performance than the hydrogen peroxide–bleached jute sample. This reduction is critical for environmental sustainability because high TDS levels increase the turbidity of receiving water bodies, which prevents sunlight from reaching aquatic plants and halts photosynthesis. This process can lead to oxygen depletion, creating a hazardous environment for native fish species. Furthermore, maintaining lower TDS at the source reduces the chemical and energy burden on industrial Effluent Treatment Plants (ETPs) (Anees Ahmad, 2024). By optimizing the sodium perborate recipe to utilize lower concentrations, the process minimizes the discharge of inorganic salts, thereby protecting aquatic ecosystems from mineral overload and ensuring a more sustainable wastewater profile (Seki Y, 2022) (Banerjee, 2016).

3.4 Whiteness Index

Whiteness Index is a quantitative measure of the whiteness of a material based on its reflectance properties. It is used to evaluate the effectiveness of bleaching or whitening. The WI value is influenced by the reflectance, color, and brightness of the material. (Bulut, 2013) (Suvam Nanda, 2025) (Roy, 2022). The Whiteness Index (WI) values for the bleached samples are presented below. The WI values are compared to a standard, with positive delta values indicating that the sample is whiter than the standard and negative delta values indicating that the sample is darker than the standard. (Bulut, 2013)
Illuminant: D65, 10°Observant
Standard: Peroxide Bleached Sample; ΔCIE WI 4.2 (Fig 10d)

Table 6: Comparison of ΔCIE WI

Sample No.	**ΔCIE WI**	**Sample No.**	**ΔCIE WI**
1	-4.69	6	-39.88
2	16.33	7	-7.16
3	32.92	8	58.91
4	-2.29	9	71.60
5	46.35	10	47.81

Table 6 exhibiting positive ΔCIE WI values (sample- 2, 3, 5, 8, 9, 10) demonstrated greater whiteness compared to the standard peroxide-treated sample, suggesting improved impurity elimination and amplified luminosity. Notably, Sample 9 (Fig 10c) displayed the maximum whiteness, succeeded by Sample 8 and 5, indicating elevated bleaching effectiveness and efficient chromophore elimination. (Seki Y, 2022) (Bulut, 2013)

In contrast, sample with negative ΔCIE WI values (sample- 1, 4, 6, 7) presented reduced whiteness, implying partial bleaching or less-than-ideal process circumstances, such as inadequate agent concentration, temperature, or duration. Sample 6 showed the minimum WI value. Overall, the variance in ΔCIE WI underscores the significance of optimizing bleaching parameters to attain homogenous and reliable outcomes. While certain samples surpassed traditional peroxide bleaching, others revealed a necessity for process enhancement to guarantee dependable whiteness enhancement.


Figure 10(a): Jute sample before bleaching


Figure 10(b): Jute sample (1-5) before bleaching


Figure 10(c): Jute sample (6-10)


Figure 10(d): Jute sample 11- after bleaching

3.5 Implications of the findings and Environmental impact

The experimental study indicated that sodium perborate represents a more potent, economical, and ecologically sound whitening compound for jute fibres in contrast to hydrogen peroxide (Brosnan, 2001) (Choudhury, 2017)

Whitening Efficacy: Sodium perborate yielded elevated Whiteness Index (WI) values— (Brosnan, 2001); (Choudhury, 2017) (Bulut, 2013)

Sample 9: 71.60 and Sample 8: 58.91 (Fig 10 c) compared with hydrogen peroxide (Sample 11: 4.2) (Fig 10d).

Tensile Strength: Fibers processed with sodium perborate preserved enhanced strength (e.g., Sample1: 539.39 N) compared with fibers treated with hydrogen peroxide (Sample 11: 234.31 N) (Fig 9).

Ecological Consequence: Effluent from sodium perborate whitening displayed diminished TDS (222 ppm) and salinity (0.27 ppt) than hydrogen peroxide (4,148.4 ppm TDS, 4.2 ppt salinity). Sodium perborate breaks down into less harmful waste products (water, oxygen, and borate) and demands reduced energy owing to its steadiness and phased oxygen liberation (Brosnan, 2001); (Choudhury, 2017)

Economic Viability: Sodium perborate (1,000 BDT/kg) is less costly and utilized in reduced amounts than hydrogen peroxide (1,500 BDT/L), rendering it more fiscally advantageous. (Brosnan, 2001) (Choudhury, 2017)

Overall, Sodium perborate exhibits improved performance, reduced expense, and decreased environmental effect, supporting its adoption as a viable whitening substitute for jute fibres.

4. CONCLUSIONS

This study establishes sodium perborate as a superior, eco-friendly alternative to hydrogen peroxide for jute bleaching. Experimental results show significantly higher efficiency, with Sample 9 (Fig 10c) reaching 71.60 WI compared to only 4.2 WI for Sample 11 (Fig 10d). Sodium perborate also preserves structural integrity better, yielding a maximum force of 539.39 N (Sample 1) versus 234.31 N (Sample 11). Environmentally, it minimizes toxicity by decomposing into water, oxygen, and borate, producing lower TDS (222 ppm) and salinity (0.27 ppt) in wastewater. Economically, its lower material requirements and reduced fiber degradation offer a cost-effective path to sustainable production. While future research should optimize process parameters and evaluate industrial scalability, this study establishes sodium perborate as a superior, eco-friendly alternative to hydrogen peroxide for greener textile processing

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AI DECLARATION

The Author used Open Paperpal to assist in technical phrasing and to better articulate the ecological implications within the discussion. All AI-generated suggestions were critically reviewed and validated by the authors, who take full responsibility for the final manuscript.

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