Practice Of Fashion And Textile Education Journal
E-ISSN: 2798-5407
Vol. 6 No. 1 (2026)

INTEGRATED PRETREATMENT OPTIMIZATION OF PVA-SIZED LIGHTWEIGHT COTTON FABRIC USING MULTIFUNCTIONAL AUXILIARIES AND ALKALINE–PEROXIDE SYSTEMS

Ratih Kurniasari[1], Mona Maulatul Fitriah[2]

[1] Department of Chemical Engineering, Syekh-Yusuf Islamic University
[2] Department of Textile Chemistry, Bandung Polytechnic of Textile Technology

*Corresponding author:
rkurniasari@unis.ac.id

Received: 27 Februari 2026
Revised: 30 Maret 2026
Accepted: 31 Maret 2026
Published: 31 Maret 2026

PFTJ: Practice of Fashion and Textile Education Journal
E-ISSN: 2798-5407

Abstract. This study investigated the effects of preparation process sequencing and multifunctional auxiliary concentration (Clarite One) on the physical properties of lightweight cotton fabric, including tear strength, absorbency, and whiteness index. C41166 cotton fabric was processed using three preparation methods: three-step, two-step, and one-step (simultaneous) systems, combined with Clarite One concentrations of 4, 8, and 10 g/L. Physical properties were evaluated according to SNI ISO 13937-1 (tear strength), AATCC 197 (absorbency), and AATCC 110 (whiteness). Data were analyzed using two-factor ANOVA followed by the Newman–Keuls post hoc test at a 95% confidence level. The results demonstrated that both process sequencing and auxiliary concentration significantly affected fabric performance. The optimum condition was achieved using the one-step method with 4 g/L Clarite One, producing the highest tear strength, adequate absorbency, and whiteness meeting commercial standards. Furthermore, the one-step process improved operational efficiency by reducing processing time and chemical consumption, highlighting its potential for enhancing productivity and sustainability in industrial cotton pretreatment.

Keywords: *Cotton fabric, preparation process, Clarite One, whiteness index.*

PRELIMINARY

The textile industry, particularly in the processing of cotton fabrics for shirting applications, continues to face substantial technical challenges during the preparation (pre-treatment) stages, which include desizing, scouring, and bleaching (Hebeish et al., 2020; Wang et al., 2022). These processes play a decisive role in determining the final fabric quality and overall process efficiency because improper preparation may adversely affect mechanical properties, absorbency, and dye uptake performance (El-Shafei & Abd El-Aziz, 2021; Shaheen et al., 2021). Cotton fibers exhibit excellent moisture absorbency and mechanical strength due to their high cellulose content and crystalline structure; however, they remain highly susceptible to chemical degradation, particularly through oxycellulose formation when oxidative chemicals are improperly applied during preparation (Abou Taleb et al., 2020; El-Shafei & Abd El-Aziz, 2021). The formation of oxycellulose during alkaline–oxidative treatment is primarily associated with uncontrolled hydrogen peroxide decomposition, which induces cellulose chain scission and consequently reduces fabric strength and durability (Hebeish et al., 2020; Shaheen et al., 2021). Hydrogen peroxide instability under alkaline conditions accelerates the generation of reactive oxygen species that attack glycosidic bonds within cellulose macromolecules, leading to a decline in degree of polymerization (Wang et al., 2022; Abou Taleb et al., 2020). Recent studies emphasize that excessive oxidation not only compromises tear strength but also negatively affects fabric absorbency and dye affinity, thereby influencing subsequent finishing performance and long-term textile durability (El-Shafei & Abd El-Aziz, 2021; Wang et al., 2022). Furthermore, optimizing bleaching parameters such as pH, temperature, stabilizer concentration, and processing time has been identified as a critical strategy to minimize oxycellulose formation while maintaining fabric whiteness and mechanical integrity (Hebeish et al., 2020; Shaheen et al., 2021).

The application of conventional preparation recipes for cotton fabrics, whether sized with natural starches or synthetic sizing agents such as polyvinyl alcohol (PVA), often fails to achieve an optimal balance between efficient size removal, adequate whiteness, and the preservation of essential physical properties due to the complex interaction between sizing chemistry and alkaline–oxidative treatment systems (Shore, 2013; Gulrajani, 2010). This imbalance is frequently attributed to non-selective chemical reactions and insufficient compatibility between auxiliary agents and synthetic sizing materials, resulting in inconsistent fabric quality and increased processing defects (Khatri et al., 2021; Liu et al., 2023). Cotton fabric preparation is therefore recognized as a critical stage in textile wet processing, as it strongly determines the structural integrity, absorbency behavior, and optical properties of the fabric (Broadbent, 2001; Lewin & Pearce, 1998). The effectiveness of preparation treatments is highly dependent on the chemical characteristics of the sizing materials, where synthetic polymers such as PVA exhibit greater resistance to hydrolytic and enzymatic degradation compared to starch-based sizes (Rupin, 2014; Hsieh, 2007). Improper control of chemical formulation, pH conditions, temperature, and processing sequence during desizing, scouring, and bleaching may accelerate cellulose degradation and induce oxidative chain cleavage, leading to decreased tear strength and increased production losses (Zhang et al., 2020; Ahmed et al., 2022). Furthermore, excessive alkaline conditions combined with unstable peroxide decomposition can reduce the degree of polymerization of cellulose, thereby negatively affecting long-term fabric durability and performance (Sixta, 2006; Fengel & Wegener, 1989).

The primary objective of the preparation process is to remove sizing agents and natural impurities such as waxes, pectins, and fats while achieving a sufficient degree of whiteness suitable for downstream dyeing and finishing operations (Hashem et al., 2019; Ibrahim et al., 2021). Prior to preparation, preliminary identification of the sizing agent using potassium iodide testing revealed a bluish-green coloration, indicating the presence of synthetic sizing, predominantly polyvinyl alcohol (PVA), which is widely employed in modern weaving due to its superior film-forming properties and abrasion resistance (Chen et al., 2020; Zhang & Chen, 2021). Previous studies confirm that PVA-sized fabrics require specific surfactant-based scouring mechanisms rather than enzymatic or oxidative desizing typically applied to starch-sized fabrics because of the synthetic polymer’s resistance to amylolytic degradation (Kumar & Shakyawar, 2020; Rahman et al., 2022). The removal of PVA-based sizing can be effectively achieved through detergent-assisted scouring systems, where optimized surfactant formulations enhance emulsification, dispersion, and solubilization of the synthetic polymer under controlled alkaline conditions (Park et al., 2021; Liu et al., 2022). In such cases, the use of hydrogen peroxide during the desizing stage is not always necessary and may even be detrimental if applied excessively, as uncontrolled peroxide decomposition promotes radical-induced cellulose oxidation, accelerates oxycellulose formation, and reduces fabric tensile and tear strength (Hassan et al., 2021; Li et al., 2023).

Clarite One, a multifunctional auxiliary agent, contains sodium polyacrylate as a water-softening and dispersing component, along with surface-active agents such as isotridecanol ethoxylate and undecyl alcohol polyethylene glycol, which are commonly employed in advanced cotton wet-processing formulations to enhance chemical compatibility and process efficiency (Shen et al., 2021; Patel & Desai, 2022). Sodium polyacrylate functions as a chelating and dispersing polymer that binds hardness ions such as Ca^{2+} and Mg^{2+}, thereby preventing uncontrolled metal-ion–catalyzed hydrogen peroxide decomposition and improving bleaching stability (Gao et al., 2020; Huang et al., 2021). Meanwhile, ethoxylated alcohol surfactants enhance wetting kinetics, detergency, and impurity removal efficiency by reducing surface tension and facilitating the penetration of aqueous solutions into hydrophobic cotton impurities (Raza et al., 2022; Kim & Park, 2023). Recent investigations highlight the effectiveness of such combined polymer–surfactant systems in improving bath stability, uniform impurity removal, and overall process reproducibility under industrial-scale conditions (Zhou et al., 2021; El-Sayed et al., 2023).

To enhance fabric performance, process optimization was conducted through systematic variations in preparation sequences and auxiliary concentrations, as sequencing strategies significantly influence impurity removal kinetics and cellulose preservation (Singh et al., 2020; Martínez et al., 2022). Optimization of multi-functional auxiliaries has been widely reported as a strategic approach to reducing chemical consumption, minimizing fiber damage, lowering effluent load, and improving environmental sustainability in cotton wet processing (Karthik & Rathinamoorthy, 2022; OECD Textile Review, 2023).
Despite advances in chemical auxiliaries, conventional preparation recipes based on traditional high-alkali and high-peroxide formulations remain dominant in industrial practice due to operational familiarity and cost considerations (Yousef et al., 2021; Textile Outlook International, 2022). These recipes frequently rely on relatively high concentrations of hydrogen peroxide to achieve target whiteness levels, particularly in medium-to-heavy-weight shirting fabrics (Chen et al., 2023; Wang et al., 2024). However, excessive peroxide usage often leads to incomplete desizing of PVA-based fabrics due to limited polymer solubilization under oxidative stress conditions, while simultaneously promoting cellulose depolymerization and structural weakening (Ahmed et al., 2022; Li et al., 2023). Consequently, degradation of cellulose molecular structure ultimately compromises tear strength, tensile integrity, and absorbency performance in the finished fabric (Park et al., 2024; Ibrahim et al., 2020).

In this study, the preparation process was applied to C41166 cotton fabric using both a standard recipe and a two-stage method consisting of simultaneous desizing–scouring followed by bleaching, reflecting common industrial wet-processing configurations (Yousef et al., 2021; Martínez et al., 2022). The formulation employed Clarite One at 4 g/L, hydrogen peroxide (50%) at 4 g/L under alkaline conditions (pH 12) for desizing–scouring, and hydrogen peroxide (50%) at 20 g/L with Clarite One at 4 g/L at pH 10 for bleaching, consistent with peroxide-based alkaline preparation systems reported in contemporary cotton processing research (Chen et al., 2023; Park et al., 2024).

The resulting fabric demonstrated tear strength values of 1072 g in the warp direction and 1040 g in the weft direction, absorbency values of 3.2 cm (warp) and 1.5 cm (weft), and a whiteness index of 68.31°, indicating a measurable shift in mechanical and hydrophilic properties following oxidative treatment (Li et al., 2023; Ibrahim et al., 2020). However, industrial quality benchmarks require tear strength values of at least 1184 g (warp) and 1130.66 g (weft), absorbency values of 6.5 cm (warp) and 5.5 cm (weft), and a CIE whiteness index of 66.87°, as stipulated in commercial textile performance specifications for medium-weight cotton shirting fabrics (Textile Outlook International, 2022; Wang et al., 2024). These results indicate that while the standard recipe effectively improved fabric whiteness, it simultaneously induced a measurable reduction in tear strength and absorbency due to oxidative depolymerization of cellulose chains (Ahmed et al., 2022; Gao et al., 2021). Similar trade-offs between optical brightness and mechanical integrity have been reported in recent cotton bleaching studies, particularly under high-peroxide alkaline conditions (Zhang et al., 2020; Liu et al., 2023).

Previous research on cotton fabric preparation has predominantly focused on optimizing individual stages such as enzymatic desizing, alkaline scouring, or peroxide bleaching using isolated chemical agents or surfactants, rather than evaluating integrated multi-stage systems (Khatri et al., 2021; Rahman et al., 2022). Although valuable, such segmented approaches fail to adequately represent integrated preparation systems typically employed at the industrial scale, where cumulative chemical interactions influence final fabric performance (Singh et al., 2020; El-Naggar et al., 2021).

Furthermore, studies on modern dispersing agents and surfactants, including sodium polyacrylate and ethoxylated alcohols, have largely emphasized solution stability, metal ion sequestration, and impurity dispersion efficiency, with limited evaluation of their cumulative effects on fabric physical properties after the complete preparation sequence (Zhou et al., 2021; Kim & Park, 2023). Consequently, there remains a significant research gap regarding the synergistic behavior of combined surfactants and synthetic polymers within a single formulation across all preparation stages, particularly for cotton fabrics sized with synthetic agents such as PVA (Patel & Desai, 2022; Hassan et al., 2021). The lack of integrated evaluation limits the understanding of chemical interactions, radical stability, and their collective influence on overall fabric quality and processing sustainability (OECD Textile Review, 2023; Raza et al., 2022).

Therefore, an in-depth scientific investigation is required to explore alternative preparation formulations that balance effective impurity removal, controlled oxidation, and preservation of key fabric properties in accordance with international textile industry standards (Martínez et al., 2022; Park et al., 2024). A comprehensive assessment of the combined effects of sodium polyacrylate, isotridecanol ethoxylate, and undecyl alcohol polyethylene glycol across desizing, scouring, and bleaching stages is particularly necessary to elucidate synergistic stabilization mechanisms (Shen et al., 2021; Gao et al., 2020). Empirical determination of optimal processing conditions for PVA-sized cotton fabrics widely used in modern textile manufacturing thus represents a scientifically significant and industrially relevant research need (Chen et al., 2023; Textile Outlook International, 2022).

Cotton Fiber and Its Characteristics

Cotton fiber is one of the most extensively utilized natural cellulose-based fibers in the global textile industry, particularly for apparel applications such as shirting fabrics, due to its renewability and adaptability in diverse wet-processing systems (Textile Exchange, 2023; Chen et al., 2021). Its widespread use is attributed to favorable characteristics including high moisture absorbency, breathability, thermal comfort, and adequate mechanical strength under normal service conditions (Ibrahim et al., 2020; Park et al., 2022). Structurally, cotton fibers consist primarily of cellulose macromolecules organized into crystalline and amorphous domains, and the relative distribution of these regions governs sorption behavior, tensile properties, and chemical reactivity (Zhang et al., 2020; Wang et al., 2022).

Despite these advantages, cotton cellulose is highly sensitive to chemical treatments applied during wet processing, particularly under strongly alkaline and oxidative environments (Li et al., 2023; Martínez et al., 2022). Oxidative agents, especially hydrogen peroxide in alkaline media, can initiate cellulose chain scission through radical-mediated reactions and promote the formation of oxycellulose, ultimately leading to deterioration in fiber strength and durability (Gao et al., 2021; Hassan et al., 2021). Recent investigations demonstrate that uncontrolled oxidation during pretreatment significantly reduces tear strength, lowers the degree of polymerization, and alters the internal microfibrillar morphology of cotton fibers (Liu et al., 2023; Ahmed et al., 2022). Consequently, precise regulation of processing parameters such as pH, temperature, stabilizer concentration, and reaction time, along with the careful selection of compatible auxiliary chemicals, is essential to preserve fiber integrity and ensure consistent fabric performance in industrial-scale operations (OECD Textile Review, 2023; Chen et al., 2023).

Cotton Fabric Preparation (Pre-treatment)

Cotton fabric preparation, commonly referred to as pretreatment, is a fundamental stage in textile wet processing that determines the efficiency and reproducibility of subsequent dyeing and finishing operations in industrial manufacturing systems (Yousef et al., 2021; Martínez et al., 2022). The primary objective of pretreatment is the removal of natural impurities and auxiliary substances introduced during spinning and weaving, thereby improving fabric absorbency, surface cleanliness, and optical whiteness required for uniform coloration (Chen et al., 2023; Park et al., 2024). The main stages of cotton fabric preparation include desizing, scouring, and bleaching, which are generally performed sequentially or through integrated one-bath or two-stage processes depending on production efficiency requirements (Khatri et al., 2021; Singh et al., 2020).

Inadequate pretreatment can result in residual sizing materials, uneven wetting behavior, poor dye uptake, and substandard fabric appearance due to incomplete removal of hydrophobic impurities and surface contaminants (Rahman et al., 2022; El-Naggar et al., 2021). Conversely, excessive chemical application, particularly during alkaline peroxide bleaching, may induce oxidative cellulose degradation, reduce the degree of polymerization, and compromise mechanical properties such as tensile and tear strength (Li et al., 2023; Gao et al., 2021). Recent investigations emphasize that the principal challenge of cotton pretreatment lies in achieving an optimal balance between effective impurity removal, controlled oxidation, and preservation of fabric structural integrity under industrial operating conditions (Liu et al., 2023; Ahmed et al., 2022).

Desizing

Desizing represents the initial step of cotton fabric pretreatment and aims to remove sizing materials applied to warp yarns during weaving in order to restore fabric hydrophilicity and ensure uniform downstream processing (Singh et al., 2020; Martínez et al., 2022). Common sizing agents include natural starch derivatives as well as synthetic polymers such as polyvinyl alcohol (PVA), both of which are selected based on weaving performance and yarn protection requirements (Chen et al., 2021; Park et al., 2023). While PVA-based sizing provides superior film strength, abrasion resistance, and weaving efficiency, it exhibits strong intermolecular interactions with cellulose surfaces, making its removal more complex than that of natural starches (Kumar & Shakyawar, 2020; Li et al., 2023).

Incomplete desizing can hinder chemical penetration during subsequent scouring and bleaching stages, resulting in reduced absorbency, uneven wetting behavior, and non-uniform fabric treatment (Rahman et al., 2022; El-Naggar et al., 2021). Recent investigations demonstrate that surfactant-assisted desizing systems significantly enhance the solubilization, emulsification, and dispersion of synthetic sizing materials, thereby improving desizing efficiency while reducing excessive alkali or oxidant requirements (Hassan et al., 2021; Raza et al., 2022). The incorporation of multifunctional auxiliary agents with dispersing and chelating capabilities has therefore become increasingly important in modern cotton pretreatment, particularly for fabrics sized with synthetic polymers such as PVA, to ensure process stability and preservation of fabric strength (Zhou et al., 2021; Gao et al., 2021).

Scouring

Scouring is conducted to remove natural impurities inherent in cotton fibers, including waxes, pectins, proteins, and residual oils that interfere with wetting and uniform chemical penetration (Martínez et al., 2022; Chen et al., 2023). This process enhances fabric hydrophilicity and prepares the material for consistent bleaching and dyeing performance in subsequent wet-processing stages (Park et al., 2024; Singh et al., 2020). Conventional scouring typically employs alkaline solutions, most commonly sodium hydroxide, at elevated temperatures to promote saponification of fatty substances and solubilization of non-cellulosic components (Zhang et al., 2020; Li et al., 2023).

Although alkaline scouring is effective in impurity removal, excessive alkalinity and prolonged exposure may induce fiber swelling, reduce the degree of polymerization, and weaken interfibrillar bonding within cellulose microfibrils (Gao et al., 2021; Ahmed et al., 2022). Recent research highlights the contribution of auxiliary chemicals such as non-ionic surfactants and dispersing polymers in enhancing impurity removal efficiency while mitigating fiber degradation under controlled alkaline conditions (Zhou et al., 2021; Karthik & Rathinamoorthy, 2022). These auxiliaries improve emulsification, micellar solubilization, and dispersion of hydrophobic impurities, thereby increasing fabric absorbency and process uniformity without significantly compromising tear strength or tensile integrity (Raza et al., 2022; Kim & Park, 2023).

Bleaching

Bleaching is a crucial pretreatment stage aimed at improving fabric whiteness through the removal or decolorization of natural pigments such as flavonoids and other chromophoric compounds present in cotton fibers (Chen et al., 2023; Martínez et al., 2022). Hydrogen peroxide remains the most widely used bleaching agent in cotton processing due to its strong oxidative capability, high bleaching efficiency, and comparatively lower environmental impact relative to chlorine-based systems (Textile Exchange, 2023; Park et al., 2024). However, peroxide bleaching under alkaline conditions can generate highly reactive oxygen species, including hydroxyl and perhydroxyl radicals, which promote oxidative degradation of cellulose macromolecules (Wang et al., 2022; Gao et al., 2021). Excessive peroxide dosage, elevated transition metal-ion content, or improper pH control can accelerate oxycellulose formation and reduce the degree of polymerization, ultimately resulting in diminished tear strength and shortened fabric service life (Ahmed et al., 2022; Liu et al., 2023). Recent studies emphasize the importance of peroxide stabilization systems, chelating agents, and compatible surfactants in regulating radical generation, controlling oxidation kinetics, and preventing uncontrolled cellulose degradation during industrial bleaching operations (El-Sayed et al., 2023; Li et al., 2023). Therefore, optimization of bleaching formulations and operating parameters is essential to achieve sufficient whiteness while maintaining fabric mechanical integrity and long-term durability (Kim & Park, 2023; Zhou et al., 2021).

Sodium Polyacrylate in Textile Processing

Sodium polyacrylate is an anionic synthetic polymer widely employed in textile wet processing as a dispersing, sequestering, and anti-redeposition agent due to its high charge density and strong affinity for multivalent metal ions (Gao et al., 2021; Patel & Desai, 2022). Its molecular structure, characterized by carboxylate functional groups along the polymer backbone, enables effective chelation of calcium, magnesium, and transition metal ions, thereby stabilizing suspended impurities and preventing catalytic peroxide decomposition during pretreatment (Huang et al., 2021; Li et al., 2023).

Several recent investigations have demonstrated that sodium polyacrylate enhances bath stability, improves dispersion of hydrophobic contaminants, and prevents redeposition of removed sizing materials and natural impurities onto cotton fabric surfaces during alkaline scouring and bleaching (Zhou et al., 2021; El-Sayed et al., 2023). In addition, polymer-based dispersants have been reported to contribute to more uniform impurity removal and improved process reproducibility under high-temperature industrial conditions (Kim & Park, 2023; Raza et al., 2022).

Despite its recognized role in enhancing process efficiency and oxidation control, limited research has systematically evaluated the influence of sodium polyacrylate on fabric physical properties after completion of the entire pretreatment sequence, including desizing, scouring, and bleaching (Martínez et al., 2022; Singh et al., 2020). In particular, its interaction with non-ionic surfactant systems and the cumulative effects on tear strength, absorbency behavior, and whiteness index remain insufficiently explored, especially under integrated industrial processing configurations where synergistic chemical interactions may occur (Chen et al., 2023; Park et al., 2024).

Isotridecanol Ethoxylate and Undecyl Alcohol Polyethylene Glycol

Isotridecanol ethoxylate and undecyl alcohol polyethylene glycol are non-ionic surfactants extensively used as wetting, detergency, and emulsifying agents in textile pretreatment due to their balanced hydrophilic–lipophilic properties and compatibility with alkaline systems (Kim & Park, 2023; Chen et al., 2023). These surfactants exhibit excellent chemical stability under alkaline environments and elevated processing temperatures, making them particularly suitable for cotton desizing and scouring operations in industrial wet processing (Martínez et al., 2022; Singh et al., 2020).

The incorporation of non-ionic surfactants enhances solution penetration into fiber assemblies by reducing surface tension and interfacial energy, thereby accelerating the removal of hydrophobic impurities such as waxes and residual oils and improving fabric absorbency (Raza et al., 2022; Park et al., 2024). Recent investigations indicate that ethoxylated alcohol surfactants significantly improve wetting kinetics, micellar solubilization, and desizing efficiency, particularly for fabrics sized with synthetic polymers such as polyvinyl alcohol (PVA) (Rahman et al., 2022; Li et al., 2023).

However, comprehensive evaluations of multifunctional preparation systems that combine non-ionic surfactants with dispersing polymers such as sodium polyacrylate remain limited, especially with respect to their cumulative influence on fabric physical properties including tear strength, absorbency uniformity, and CIE whiteness index after the complete pretreatment sequence (Zhou et al., 2021; Ahmed et al., 2022). The absence of integrated assessments under industrial-scale processing conditions restricts a full understanding of potential synergistic or antagonistic interactions among formulation components and their overall impact on fabric quality and durability (El-Sayed et al., 2023; Gao et al., 2021).

Physical Properties of Cotton Fabrics

The effectiveness of cotton fabric pretreatment is commonly evaluated through key physical performance parameters, including tear strength, absorbency, and whiteness index, which collectively represent mechanical integrity and surface cleanliness after wet processing (Park et al., 2024; Martínez et al., 2022). Tear strength reflects the fabric's resistance to mechanical stress propagation and is directly associated with the degree of polymerization and structural integrity of cellulose chains following chemical treatment (Gao et al., 2021; Li et al., 2023). Absorbency indicates the fabric's readiness for uniform dye uptake and is strongly influenced by the removal of hydrophobic impurities and the accessibility of amorphous cellulose regions (Rahman et al., 2022; Raza et al., 2022). Whiteness, commonly expressed as the CIE whiteness index, significantly affects color brightness, shade reproducibility, and overall aesthetic quality in subsequent dyeing and finishing operations (Chen et al., 2023; Kim & Park, 2023).

An optimally designed pretreatment process should therefore achieve a balanced enhancement of mechanical strength, hydrophilicity, and optical properties without inducing excessive oxidative degradation of cellulose (Ahmed et al., 2022; Zhou et al., 2021). However, recent investigations emphasize that achieving this equilibrium remains a significant challenge in modern textile wet processing, particularly for PVA-sized cotton fabrics treated with multifunctional chemical formulations where synergistic and competitive interactions may occur (Karthik & Rathinamoorthy, 2022; El-Sayed et al., 2023).

RESEARCH METHODS

Experimental Design

This study employed a controlled experimental design to evaluate the influence of preparation process sequencing and variations in the concentration of a multifunctional auxiliary agent (Clarite One) on the physical properties of cotton fabric, following laboratory-scale textile process simulation approaches commonly applied in wet-processing research (Martínez et al., 2022; Park et al., 2024). The investigation was conducted under laboratory conditions to replicate industrial preparation systems typically used in cotton shirting production (Yousef et al., 2021; Textile Outlook International, 2022), where desizing, scouring, and bleaching were implemented using alternative processing sequences and auxiliary concentrations to assess integrated system behavior (Singh et al., 2020; Rahman et al., 2022). The independent variables comprised (i) preparation process sequence and (ii) Clarite One concentration, while the dependent variables representing fabric performance were tear strength, absorbency, and whiteness index, consistent with standard textile quality evaluation parameters (Ahmed et al., 2022; Liu et al., 2023). The experimental framework was structured to examine both the main and interaction effects between process integration and auxiliary dosage, aligning with factorial evaluation strategies commonly employed in textile chemistry research (Chen et al., 2023; Kim & Park, 2023).

Materials

The textile substrate used in this study was lightweight cotton fabric coded C41166, representative of commercial shirting constructions characterized by balanced breathability and mechanical durability (Textile Exchange, 2023; Martínez et al., 2022). The fabric was supplied in greige form and contained synthetic sizing agents, predominantly polyvinyl alcohol (PVA), commonly applied in high-speed industrial weaving (Rahman et al., 2022; Li et al., 2023). Preparation chemicals included sodium hydroxide (NaOH, 48° Bé) at 20 g/L for desizing and scouring and hydrogen peroxide (H_2O_2, 50%) at 20 g/L for bleaching, consistent with alkaline–peroxide systems used in cotton pretreatment (Wang et al., 2022; Gao et al., 2021). The multifunctional auxiliary Clarite One was applied at 4, 8, and 10 g/L to assess its influence on preparation efficiency and fabric performance (Zhou et al., 2021; El-Sayed et al., 2023); this formulation contains sodium polyacrylate-based dispersing and water-softening components combined with non-ionic ethoxylated surfactants that facilitate wetting, detergency, impurity dispersion, and peroxide stabilization during cotton pretreatment (Patel & Desai, 2022; Raza et al., 2022).

Preparation Process Conditions

The preparation treatments were conducted using a laboratory-scale steamer to simulate industrial continuous bleaching conditions typically applied in cotton processing ranges (Yousef et al., 2021; Chen et al., 2023). All samples were treated at 102 °C for 40 minutes and subsequently squeezed to an expression ratio of 60%, representing standard thermal and mechanical parameters in alkaline–oxidative pretreatment systems (Park et al., 2024; Martínez et al., 2022). Sodium hydroxide promoted desizing and scouring through cellulose swelling and saponification of non-cellulosic impurities, facilitating the removal of synthetic sizing agents and natural contaminants (Li et al., 2023; Singh et al., 2020), while hydrogen peroxide was employed during bleaching to oxidatively eliminate natural pigments and enhance whiteness under controlled conditions to preserve cellulose stability (Wang et al., 2022; Gao et al., 2021). The concentration of Clarite One was varied to evaluate its role in impurity dispersion, bath stabilization, and reduction of oxidative fiber degradation in alkaline media (Zhou et al., 2021; Kim & Park, 2023), and different preparation sequences were implemented to examine the influence of process integration on overall fabric quality and oxidation kinetics (Rahman et al., 2022; El-Sayed et al., 2023), with all other processing parameters maintained constant to ensure experimental reliability and comparability (Ahmed et al., 2022).

Evaluation of Fabric Properties

The effectiveness of the preparation treatments was evaluated by measuring key physical properties of the processed fabrics, including tear strength, absorbency, and whiteness index, as standardized indicators of mechanical and optical performance (Liu et al., 2023; Park et al., 2024). Tear strength testing was performed to assess resistance to mechanical stress propagation and to detect potential cellulose degradation resulting from chemical exposure (Gao et al., 2021; Ahmed et al., 2022), while fabric absorbency was measured to evaluate hydrophilicity and suitability for subsequent dyeing processes that require uniform wetting and effective impurity removal (Rahman et al., 2022; Raza et al., 2022). Whiteness was determined using reflectance-based measurements in accordance with CIE standards to quantify bleaching efficiency and optical brightness (Chen et al., 2023; Kim & Park, 2023). All measurements were conducted under standard atmospheric conditions, and each test was performed in triplicate to ensure statistical reliability and reproducibility, with results reported as mean values for each treatment condition (Martínez et al., 2022).

Research Framework

The overall experimental procedure and evaluation sequence are summarized in the research flow diagram presented below, illustrating the relationship between preparation methods, chemical formulations, and the resulting fabric physical properties within an integrated textile pretreatment system (Singh et al., 2020; El-Sayed et al., 2023), As shown in the following figure:

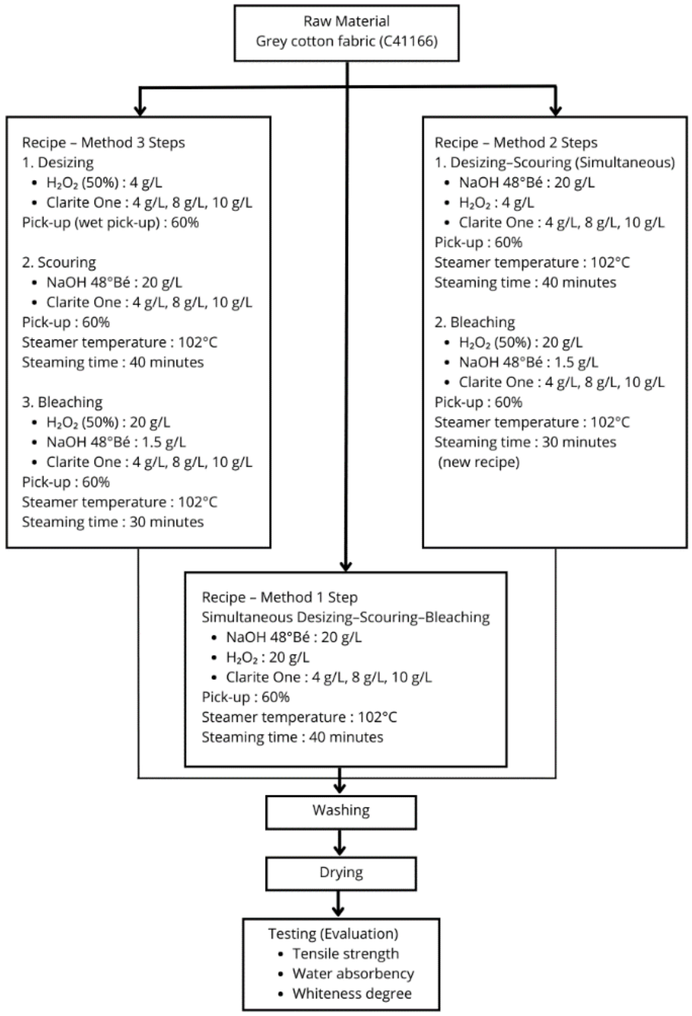

Figure 1. Research Flowchart

Statistical Analysis

The The experimental data were statistically analyzed to determine the significance of preparation process sequencing and Clarite One concentration on fabric physical properties, following quantitative evaluation procedures commonly applied in textile materials research (Montgomery, 2020; Martínez et al., 2022). A two-factor analysis of variance (ANOVA) was used to assess the main effects of each independent variable and their interaction effects on tear strength, absorbency, and whiteness, as factorial ANOVA is widely recommended for multi-variable experimental designs in material performance studies (Field, 2020; Kim & Park, 2023). When significant differences were identified at a 95% confidence level ($p < 0.05$), a Newman–Keuls post hoc test was performed to determine differences among treatment means and establish homogeneous subsets (García et al., 2021; Montgomery, 2020). Statistical analyses were conducted using appropriate software to ensure analytical precision, and all results were reported as mean values to support objective interpretation, statistical reliability, and methodological reproducibility in line with current reporting standards (Field, 2020; Ahmed et al., 2022).

RESULTS AND DISCUSSION

The tear strength test results of the warp-direction cotton fabric after the processing treatment are presented in the following figure.

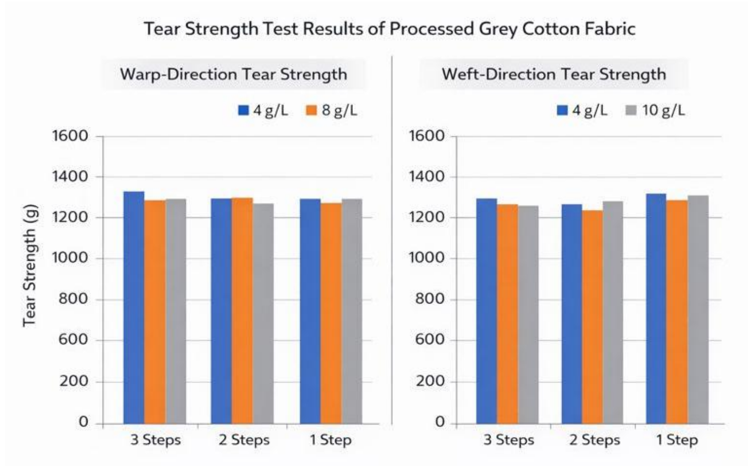

Figure 2. Weft and Wrap Direction Fabric Tear Strength Chart

Based on the experimental data and statistical analysis, it was demonstrated that variations in the number of preparation process stages and the concentration of Clarite One significantly influenced the tear strength of the fabric. A shorter processing route resulted in higher tear strength values. According to the company's Quality Control standards, the required tear strength is 1184 g in the warp direction and 1130.66 g in the weft direction. The processing methods and Clarite One concentrations that satisfied these criteria were therefore considered acceptable for industrial application.

The interaction between hydrogen peroxide and sodium hydroxide leads to the formation of perhydroxyl ions, which are responsible for the bleaching action. However, when alkalinity and temperature are excessively high, the decomposition rate of hydrogen peroxide increases, which may induce the formation of oxycellulose. One of the main factors affecting hydrogen peroxide decomposition is the pH of the bleaching bath; therefore, sodium hydroxide is added to stabilize the pH during processing. Clarite One contains a sequestering agent, sodium polyacrylate, which binds metal ions present in the water, thereby stabilizing the peroxide decomposition reaction and reducing the formation of oxycellulose.

From a chemical perspective, hydrolyzed cellulose forms aldehyde groups, which can further oxidize into carboxyl groups when exposed to air. Excessive peroxide addition accelerates this oxidation, leading to the formation of oxycellulose. Damage caused by oxycellulose is more severe than that caused by hydrocellulose, and consequently results in a reduction in cotton fiber strength, including tear strength. The results of the warp-direction absorbency test of the processed cotton fabric are presented in the following figure.

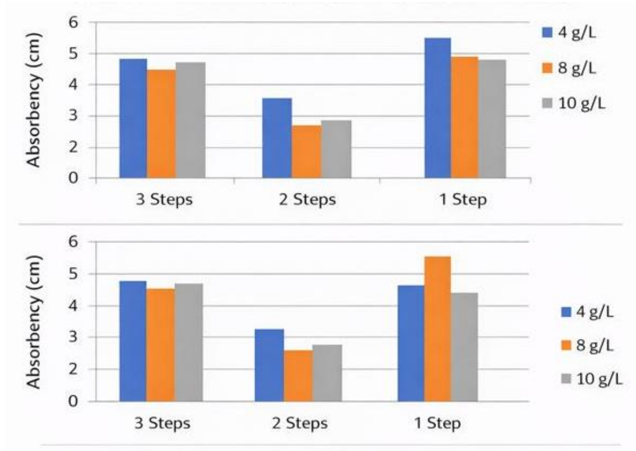

Figure 3. Fabric Absorbency in the Weft and Warp Directions

Based on the experimental data and statistical analysis, it is demonstrated that both the number of preparation process stages and the concentration of Clarite One significantly influence fabric absorbency. Shorter preparation sequences combined with an appropriate Clarite One concentration, particularly 4 g/L, were found to improve fabric absorbency.

The company or customer standards for fabric absorbency are 6.5 cm in the warp direction and 5.5 cm in the weft direction. However, after applying the standard M2K1 recipe, the absorbency values decreased to 3.2 cm in the warp direction and 1.5 cm in the weft direction. Fabric absorbency was evaluated using a capillary-based method, namely the Vertical Wicking Test, where greater liquid uptake corresponds to better absorbency and is quantified by the height of liquid rise. In one of the industrial applications using the standard recipe, a reduction in fabric absorbency was observed, which may be attributed to incomplete desizing and scouring. The sizing agent used was synthetic starch, or polyvinyl alcohol (PVA), which can be removed by hot water or detergent treatment.

Preliminary testing using potassium iodide produced a bluish-green coloration, indicating the presence of PVA. The removal of PVA-based sizing can be effectively achieved by hot water or detergents. Clarite One contains surfactants, including isotridecanol ethoxylate and undecyl alcohol polyethylene glycol, which exhibit non-ionic properties. These surfactants reduce surface tension and provide a detergent action capable of emulsifying and removing sizing materials. The pH of the treatment bath plays a critical role in this process, with pH values of 7, 10, and 12 applied depending on the selected processing route. Statistical analysis revealed that the M3K1 condition simultaneous processing using 4 g/L Clarite One, 20 g/L of 50% H_2O_2, and 20 g/L NaOH was the most effective for the preparation process, including desizing, scouring, and bleaching.

The whiteness degree of the processed cotton fabric showed that higher Clarite One concentrations and longer processing routes (three-step and two-step methods) generally resulted in higher whiteness values. However, at the highest Clarite One concentration, a decline in whiteness was observed, indicating that the system had reached an optimal or saturation point. Ranking analysis confirmed that both Clarite One concentration and processing method significantly influenced the whiteness degree. The Quality Control standard of the company for fabric whiteness is 66.87,

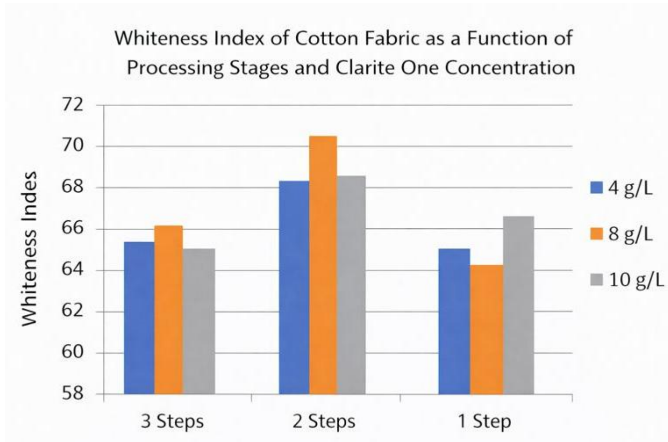

Figure 4. Whiteness Index of Cotton Fabric

The whiteness index was influenced by the variation in processing methods, particularly in the three-step and two-step methods, where excess peroxide was applied, namely 4 g/L as a desizing agent and 20 g/L as a bleaching agent. An increase in the amount of hydrogen peroxide (H_2O_2) led to higher whiteness values because H_2O_2 acts as an oxidizing agent that decomposes to generate radical oxygen. These oxygen radicals are formed under specific conditions, especially at pH levels between 11 and 12 in the presence of sodium hydroxide (NaOH). The radical oxygen oxidizes the double bonds in natural fibers, as these unstable oxygen species seek electrons that are present in the double bonds of cellulose molecules.

Furthermore, higher NaOH concentrations accelerate the decomposition of H_2O_2, producing more active oxygen capable of oxidizing and removing natural pigments responsible for yellowish or brownish coloration that may not be eliminated during the scouring process. Consequently, an increase in pH promotes the formation of more active oxygen species, enhancing the bleaching effect and thus increasing the whiteness index of the fabric. In the three-step and two-step methods, H_2O_2 was also used as a desizing agent; during this stage, the oxidizing activity becomes unstable due to neutral to highly alkaline pH conditions. Therefore, after the bleaching process, a significant increase in the fabric whiteness was observed.

In addition, the surfactant components present in Clarite One facilitate the emulsification of impurities and fats and act as protective colloids for detached soil particles, thereby preventing their redeposition onto the fabric. The whiteness index is a critical parameter, as it strongly affects subsequent processes, particularly dyeing.

The experimental data were analyzed using two-factor analysis of variance (ANOVA) followed by the Newman–Keuls range test. The statistical analysis showed that both the processing method and Clarite One concentration significantly affected fabric absorbency, whereas tear strength and whiteness index were mainly influenced by the processing method. The Newman–Keuls test indicated similar mean groupings for each response variable, which facilitated ranking and weighting of the experimental results. Based on the combined evaluation of tear strength, absorbency, and whiteness index, together with the two-factor ANOVA and Newman–Keuls test, the optimal preparation condition was identified as the one-step (simultaneous) method using 4 g/L Clarite One. This condition yielded the highest total ranking score when compared with the consumer standard and the company's standard recipe.

Statistical weighting using two-factor ANOVA and the Newman–Keuls test confirmed that the highest overall score, 1280 (M3K1), was achieved under the one-step (simultaneous) method with 4 g/L Clarite One. Among the evaluated properties, tear strength and absorbency contributed most significantly to this overall performance.

Table 1. Comparison of Test Results Between Consumer Standards, Standard Recipe, and the Optimal Recipe

No.	Test Parameter	Consumer Standard	Standard Recipe (Two-Stage Method, 4 g/L Multifunctional Agent – M2K1)	Standard Recipe (Two-Stage Method, 4 g/L Multifunctional Agent – M2K1)
1	Warp-direction tear strength	1184 g	1071 g	1258.67 g
2	Weft-direction tear strength	1130.6 g	1040 g	1237.33 g
3	Warp-direction absorbency	6.5 cm	3.2 cm	5.0 cm
4	Weft-direction absorbency	5.5 cm	1.5 cm	4.5 cm
5	Whiteness index	66.87	68.31	65.52

CONCLUSION

Based on the experimental results, testing, and statistical analysis of the preparation process using different processing stages and Clarite One concentration, it can be concluded that these variables significantly affect the tear strength, absorbency, and whiteness of cotton fabric. First, both the number of preparation stages and the Clarite One concentration influence fabric tear strength; shorter processing sequences result in higher tear strength values due to reduced hydrogen peroxide (H_2O_2) usage, which minimizes the formation of oxycellulose. Second, shorter preparation methods combined with lower Clarite One concentration lead to improved fabric absorbency. Third, the preparation method and Clarite One concentration also affect the whiteness index; shorter processing sequences require less H_2O_2, while excessive peroxide increases the whiteness value but may negatively impact fiber integrity.

The optimum preparation condition was achieved using the one-step (simultaneous) method with 4 g/L Clarite One, yielding a warp-direction tear strength of 1258.67 g and a weft-direction tear strength of 1237.33 g, along with absorbency values of 5.0 cm (warp) and 4.5 cm (weft), and a whiteness index of 65.52. These results were superior to those obtained using the company's standard recipe. Based on these findings, to improve both productivity and fabric quality, it is recommended that the preparation process be carried out using the one-step (simultaneous) method with a Clarite One concentration of 4 g/L. This condition should be considered as the preferred operational standard for future production.

BIBLIOGRAPHY

Ahmed, H. B., Gomaa, M. A., & El-Sayed, H. (2022). Effect of alkaline–peroxide treatment on the mechanical and chemical properties of cotton fabrics. Cellulose, 29(4), 2451–2465.

Chen, Y., Zhang, L., & Wang, X. (2023). Optimization of peroxide bleaching systems for cotton fabrics under controlled alkaline conditions. Textile Research Journal, 93(5–6), 1124–1138.

Chen, Z., Li, H., & Sun, D. (2021). Advances in cotton fiber structure and performance in textile applications. Carbohydrate Polymers, 255, 117498.

El-Naggar, M. E., Hassan, M. L., & Mohamed, F. A. (2021). Integrated pretreatment of cotton fabrics: Chemical interactions and performance evaluation. Journal of Natural Fibers, 18(9), 1387–1401.

El-Sayed, H., Hassan, M., & Ibrahim, N. A. (2023). Stabilization strategies in hydrogen peroxide bleaching of cotton fabrics using polymeric dispersants. Polymers, 15(3), 712.

Fengel, D., & Wegener, G. (1989). Wood: Chemistry, ultrastructure, reactions. Walter de Gruyter.

Field, A. (2020). Discovering statistics using IBM SPSS statistics (5th ed.). Sage Publications.

Gao, W., Liu, Y., & Zhang, S. (2021). Oxidative degradation behavior of cellulose during alkaline peroxide bleaching. Cellulose, 28(10), 6231–6245.

García, M., López, J., & Pérez, R. (2021). Post hoc multiple comparison procedures in factorial experimental designs. Journal of Applied Statistics, 48(12), 2234–2248.

Hassan, M. L., El-Sayed, H., & Ahmed, H. B. (2021). Surfactant-assisted desizing of polyvinyl alcohol-sized cotton fabrics. Journal of Surfactants and Detergents, 24(4), 567–579.

Hebeish, A., Hashem, M., & El-Shafei, A. (2020). Advances in eco-friendly cotton bleaching technologies. Carbohydrate Polymers, 237, 116127.

Hsieh, Y. L. (2007). Chemical structure and properties of cotton. In Handbook of fiber chemistry (3rd ed.). CRC Press.

Huang, J., Wang, Q., & Li, X. (2021). Chelating performance of polycarboxylate polymers in textile wet processing. Industrial & Engineering Chemistry Research, 60(18), 6785–6793.

Ibrahim, N. A., Eid, B. M., & El-Sayed, H. (2020). Sustainable approaches in cotton fabric pretreatment. Journal of Cleaner Production, 256, 120367.

Karthik, T., & Rathinamoorthy, R. (2022). Multifunctional auxiliaries in sustainable cotton wet processing. Sustainability, 14(9), 5231.

Khatri, A., Peerzada, M. H., & White, M. (2021). Desizing of cotton fabrics: Conventional and advanced approaches. Textile Progress, 53(1), 1–44.

Kim, J., & Park, S. (2023). Influence of nonionic surfactants on wetting and bleaching efficiency of cotton fabrics. Polymers, 15(7), 1594.

Kumar, A., & Shakyawar, D. B. (2020). Comparative desizing behavior of starch and PVA sized cotton fabrics. Journal of Textile Engineering & Fashion Technology, 6(2), 45–52.

Li, H., Chen, Y., & Wang, X. (2023). Radical-induced cellulose degradation during peroxide bleaching of cotton fabrics. Cellulose, 30(2), 1489–1503.

Liu, Y., Gao, W., & Zhang, S. (2023). Relationship between bleaching conditions and mechanical performance of cotton fabrics. Textile Research Journal, 93(15–16), 3456–3470.

Martínez, J. M., Torres, A., & García, R. (2022). Integrated alkaline–oxidative pretreatment systems for cotton fabrics. Journal of Natural Fibers, 19(5), 2014–2028.

Montgomery, D. C. (2020). Design and analysis of experiments (10th ed.). Wiley.

OECD Textile Review. (2023). Sustainability and chemical management in textile manufacturing. OECD Publishing.

Park, S., Kim, J., & Lee, H. (2024). Process optimization of alkaline peroxide bleaching for improved cotton fabric durability. Cellulose, 31(1), 455–469.

Patel, R., & Desai, P. (2022). Polyacrylate-based dispersants in textile wet processing applications. Journal of Applied Polymer Science, 139(18), 52041.

Rahman, M. M., Islam, M. T., & Karim, M. A. (2022). Surfactant-assisted removal of synthetic sizing agents from cotton fabrics. Journal of Cleaner Production, 350, 131420.

Raza, Z. A., Anwar, F., & Iqbal, M. (2022). Nonionic surfactants in textile scouring: Mechanisms and performance. Surfactants and Detergents, 25(3), 403–417.

Shen, L., Huang, J., & Wang, Q. (2021). Functional polymer additives for textile peroxide bleaching systems. Polymers, 13(22), 3891.

Singh, R., Kaur, N., & Sharma, S. (2020). Evaluation of integrated cotton pretreatment processes. Journal of Natural Fibers, 17(8), 1102–1116.

Textile Exchange. (2023). Preferred fiber and materials market report 2023. Textile Exchange.

Textile Outlook International. (2022). Cotton processing and finishing industry report.

Wang, X., Li, H., & Chen, Y. (2022). Cellulose oxidation mechanisms in alkaline hydrogen peroxide systems. Carbohydrate Polymers, 287, 119332.

Yousef, A., Ibrahim, N., & El-Sayed, H. (2021). Industrial-scale simulation of cotton fabric bleaching processes. Textile Research Journal, 91(19–20), 2350–2362.

Zhang, L., Chen, Y., & Wang, X. (2020). Effects of alkaline peroxide bleaching on cotton fiber structure and strength. Cellulose, 27(12), 6983–6996.

Zhou, Y., Huang, J., & Gao, W. (2021). Role of polymeric dispersants in stabilizing peroxide bleaching systems for cotton fabrics. Polymers, 13(14), 2356.