



Coconut-Based Methyl Ester Sulfonate for Eco-Friendly Textile Scouring

¹Sangeeta Patil, ²Harshal Patil, ¹Ashok Athalye and ²Jyotsna Waghmare

¹Department of Fibres & Textile Processing Technology

²Department of Oils, Oleochemicals and Surfactant Technology

Institute of Chemical Technology (ICT), Mumbai-400019, Maharashtra, India.

(Received: 25 August 2025 Revised: 27 September 2025 Accepted: 14 October 2025)

KEYWORDS

Bio-based surfactant, Coconut fatty acid distillate, Sustainable processing, Textile pretreatment, Wool Scouring

ABSTRACT:

The textile industry faces increasing pressure to adopt sustainable practices while maintaining product quality and economic viability. This study investigates the synthesis and application of methyl ester sulfonate (MES) derived from coconut fatty acid distillate (CFAD) as an eco-friendly alternative to conventional petroleum-based surfactants in textile scouring processes. CFAD, a renewable byproduct of coconut oil refining rich in medium-chain fatty acids, was converted to MES through acid-catalyzed esterification followed by sulfonation using sodium bisulfite. The synthesized MES exhibited excellent surface activity with surface tension reduction to 35.21 mN/m at 0.1% concentration, 64% emulsifying index, and superior biodegradability characteristics. Performance evaluation on cotton hosiery fabric, wool fibers, and polyester fabric demonstrated that MES achieved comparable or superior results to commercial surfactants. At 5.0% concentration, MES showed enhanced capillary rise (3.5 cm), improved whiteness index (68.48), and effective grease removal in wool scouring (15.8% weight loss) with reduced yellowness index (14.6). The bio-based MES surfactant offers significant environmental advantages including enhanced biodegradability, reduced aquatic toxicity, and utilization of renewable agricultural waste, making it a promising sustainable alternative for textile wet processing applications while maintaining industrial performance standards.

1. Introduction

The textile industry, recognized as one of the world's largest and most influential manufacturing sectors, faces unprecedented challenges in balancing economic growth with environmental sustainability. With global textile production exceeding 100 million tons annually and generating substantial environmental impacts, the industry confronts mounting pressure from regulatory bodies, consumer advocacy groups, and environmental organizations to adopt sustainable practices while maintaining product quality and economic viability [1,2]. Traditional textile processing, particularly during the crucial scouring stage, relies heavily on synthetic surfactants, harsh alkaline chemicals, and petroleum-derived detergents that pose significant environmental challenges and contribute to widespread ecological degradation. The scouring process, fundamental to textile manufacturing and essential for removing natural impurities including pectins, waxes, oils, proteins, and sizing agents from textile fibers, conventionally employs petroleum-based detergents, sodium hydroxide solutions, and various synthetic surfactants [3,4]. These

conventional scouring agents, while effective in achieving desired cleaning performance, generate substantial volumes of contaminated wastewater containing high biological oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS). The resulting effluent discharge poses serious threats to aquatic ecosystems, groundwater quality, and public health, particularly in developing countries where textile manufacturing is concentrated and environmental regulations may be less stringent [5,6]. In response to escalating environmental concerns, increasingly stringent regulatory frameworks such as the European Union's Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) regulation, and growing consumer awareness regarding sustainable products, the textile industry is actively embracing green chemistry principles to develop eco-friendly alternatives. Green chemistry, comprehensively defined by the twelve fundamental principles established by Anastas and Warner in 1998, emphasizes the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances



throughout their entire lifecycle [7-9]. This paradigm shift has catalyzed extensive research into bio-based surfactants derived from renewable resources, offering promising and commercially viable solutions for sustainable textile processing. The transition toward sustainable textile processing has gained significant momentum with the development of bio-based surfactants that demonstrate comparable or superior performance to conventional synthetic alternatives. These renewable surfactants, derived from agricultural feedstocks, vegetable oils, and industrial byproducts, offer numerous advantages including enhanced biodegradability, reduced aquatic toxicity, lower carbon footprint, and improved compatibility with biological wastewater treatment systems. The utilization of renewable feedstocks for surfactant production also contributes to reduced dependence on petroleum resources and supports agricultural economies in developing regions [10,11]. Coconut fatty acid distillate (CFAD), a valuable byproduct generated during the refining process of coconut oil, represents an abundant, cost-effective, and underutilized renewable resource with significant potential for bio-based surfactant production. Global coconut production exceeds 60 million tons annually, generating substantial quantities of CFAD that are often undervalued or used in low-value applications. Rich in medium-chain fatty acids, particularly lauric acid (C12:0) comprising 45-50% of the fatty acid profile, and myristic acid (C14:0) accounting for 15-20%, CFAD possesses inherent surfactant properties that make it an exceptionally attractive feedstock for bio-based detergent synthesis. The unique fatty acid composition of CFAD, characterized by its high proportion of medium-chain saturated fatty acids, provides excellent surface activity, foam stability, and cleaning performance characteristics [12,13].

The conversion of CFAD to methyl ester sulfonate (MES) through carefully controlled sulfonation reactions using sulfur trioxide or chlorosulfonic acid offers a well-established pathway to produce high-performance, biodegradable surfactants with excellent cleaning capabilities and superior environmental profiles. The synthesis process involves initial esterification of fatty acids to form fatty acid methyl esters (FAME), followed by sulfonation at the alpha-carbon position to produce alpha-sulfonated methyl esters [14,15]. This two-step

process can be optimized to achieve high conversion rates, minimize byproduct formation, and ensure consistent product quality suitable for industrial applications. Methyl ester sulfonates have emerged as highly promising alternatives to conventional linear alkylbenzene sulfonates (LAS), alcohol ethoxylates (AE), and sodium lauryl sulfate (SLS), commonly used in textile scouring applications. MES compounds exhibit superior biodegradability with over 90% degradation within 28 days under standard OECD testing conditions, significantly lower aquatic toxicity with LC50 values typically exceeding 100 mg/L, and enhanced performance in hard water conditions due to their unique molecular structure and reduced sensitivity to calcium and magnesium ions.

The distinctive molecular architecture of MES, featuring both ester and sulfonate functional groups, provides excellent wetting properties with surface tension reduction to below 30 mN/m, superior emulsifying capabilities for oil and grease removal, and effective dispersing properties essential for preventing soil redeposition during textile scouring operations. The integration of coconut-derived MES into textile scouring processes aligns perfectly with circular economy principles by valorizing agricultural waste streams, reducing dependence on fossil fuel-based chemicals, and creating value-added products from renewable resources. This approach not only addresses critical environmental sustainability concerns but also offers substantial economic benefits through reduced raw material costs, improved process efficiency, enhanced product performance, and potential for local production in coconut-growing regions. The development of CFAD-based MES also supports sustainable development goals by creating economic opportunities in rural communities while reducing environmental impacts associated with conventional textile processing [17-19].

Contemporary textile scouring formulations typically contain 15-25% active surfactant content, with the remainder consisting of builders, chelating agents, pH adjusters, and processing aids. The replacement of conventional synthetic surfactants with bio-based MES in these formulations requires careful consideration of compatibility, performance characteristics, and processing conditions. Preliminary studies have indicated that CFAD-based MES can effectively replace synthetic surfactants in scouring formulations while



maintaining or improving key performance parameters including soil removal efficiency, fabric whiteness improvement, and fiber protection [20-23]. Despite the promising characteristics and potential advantages of bio-based MES derived from coconut fatty acid distillate, comprehensive studies systematically evaluating their performance in textile scouring applications remain surprisingly limited in the scientific literature. Critical performance parameters such as soil removal efficiency under various conditions, fabric whiteness improvement and color brightness enhancement, fiber damage prevention and fabric hand preservation, foaming characteristics and foam stability, and process optimization for different textile substrates require systematic investigation to establish their commercial viability and competitive positioning. Furthermore, detailed comparative assessments with conventional scouring agents are essential to validate their effectiveness, identify optimal application conditions, and develop implementation guidelines for industrial adoption [24-27].

The present comprehensive study aims to bridge this significant knowledge gap by systematically investigating the synthesis, detailed characterization, and practical application of methyl ester sulfonate derived from coconut fatty acid distillate as an eco-friendly textile scouring agent. Through rigorous experimental evaluation encompassing laboratory-scale synthesis optimization, comprehensive physicochemical characterization, extensive performance testing on various textile substrates, and detailed environmental impact assessment, this research seeks to demonstrate the substantial potential of CFAD-based MES as a sustainable, high-performance alternative to conventional scouring chemicals, thereby contributing significantly to the development of environmentally responsible textile processing technologies.

2. Materials and Methods

2.1 Material

- Coconut Fatty Acid Distillate (CFAD) containing 85-90% free fatty acids, with lauric acid as the predominant component (45-50%), obtained from a local coconut oil processing facility.
- HPLC grade methanol (99.9% purity) from Sigma-Aldrich served as the alcohol reactant, while para-

toluene sulfonic acid (PTSA) acted as the esterification catalyst.

- Additional materials included analytical grade sodium hydroxide pellets ($\geq 98\%$) from Merck for neutralization processes and technical grade sodium bisulfite from LOBA Chem for sulfonation procedures.
- Commercial textile scouring agents such as anionic wetting agent -Zywet OTI liquid, Alpha Olephine Sulphonate (AOS) and nonionic detergent Zywet NIS were sourced from Rossari Biotech Limited..
- All analytical grade chemicals for characterization and analysis were obtained from reputable suppliers to ensure experimental reliability and accuracy.
- Cotton Greigh hosiery fabric: 100% cotton Single jersey 30s cotton (160140 g/m^2) was sourced from a Vijay mill -Tirupur local textile mill.
- Polyester fabric: 100% polyester stained greige fabric was sourced from Aishwarya mill, Surat.
- Greasy wool fibres sourced from Jayashree Textile, Calcutta.

2.2 Methods

2.2.1 Synthesis of Coconut Fatty Acid Distillate Methyl Ester (CFADME)

The methyl esterification of CFAD was performed through acid-catalyzed esterification using a systematic approach. The reaction was initiated by combining 100 g of CFAD with methanol at a 1:6 molar ratio in a 500 mL round-bottom flask fitted with a reflux condenser. Para-toluene sulfonic acid (PTSA) (2% w/w of CFAD) served as the acidic catalyst to facilitate the esterification process. The reaction mixture was heated to 65°C and maintained under reflux conditions for 4 hours with continuous stirring at 300 rpm to ensure complete conversion of free fatty acids to methyl esters. Upon completion, the reaction mixture was cooled to room temperature and transferred to a separatory funnel for product isolation. The organic layer was thoroughly washed with distilled water until a neutral pH was achieved to remove residual acid catalyst. The crude methyl ester product underwent purification by drying over anhydrous sodium sulfate followed by filtration to remove moisture and solid impurities. Excess methanol was subsequently removed under reduced pressure using



a rotary evaporator, yielding purified CFAD methyl ester suitable for further sulfonation processes.[28]

2.2.2 Sulfonation of CFADME to Produce Methyl Ester Sulfonate (MES)

The sulfonation of CFAD methyl ester was conducted following the method reported by Wibowo et al. [29,30], to produce methyl ester sulfonate surfactants. The sulfonation reactions were performed in a two-neck round-bottom flask equipped with a magnetic stirrer, where predetermined amounts of methyl ester (ME), sodium bisulfite, and alumina were charged into the reaction system and stirred at 400 rpm. Following the sulfonation process, the resulting reaction mixture was centrifuged at 7500 rpm for 10 minutes to remove residual sodium bisulfite and other solid impurities. The centrifuged product, identified as methyl ester sulfonic acid (MESA), underwent purification treatment with methanol in a flask maintained at 55°C for 1.5 hours to ensure complete removal of unreacted materials and by-products. The final step involved neutralization of the purified MESA product using 20% sodium hydroxide solution, which was added dropwise under continuous stirring until the pH reached approximately 8.0. This neutralization process converted the acidic MESA into the corresponding sodium salt form, yielding methyl ester sulfonate (MES) as a sticky, pale yellow liquid product. The methanol was subsequently recovered using a rotary evaporator, and the final MES product was stored in a covered container for quality analysis.

2.3 Characterization of MES

•FTIR analysis: was performed using a Shimadzu IR-470 spectrometer in the range of 4000-400 cm^{-1} to identify functional groups and confirm the chemical structure of the synthesized MES.

•Water absorbency: assessed using Drave's Test (AATCC 17), measuring the time required for a standardized cotton yarn skein to sink in the surfactant solution, with shorter times indicating higher wetting efficiency.

•Foaming behavior: evaluated using a manual shaking method following GOST 1770-74, where 1.0 g/L aqueous solutions were shaken in graduated cylinders and foam height was measured immediately and after one minute, determining foaming tendency and stability.

•Surface tension: determined by the pendant drop method using an Optical Contact Angle Measuring System (Model OCA 25 15EC, DataPhysics Instruments), analyzing droplet shape to calculate surface tension reduction from water's baseline of 72 dyn/cm.

•Emulsifying capacity: quantified using the emulsification index (E24), calculated as the percentage ratio of emulsion layer height to total liquid height after 24 hours of standing.

•Specific gravity: determined according to ASTM D792 at 30°C, ionic nature identification, pH measurement using a digital pH meter with 10% (w/v) aqueous solutions, pH stability assessment over 30 days at controlled pH values (4, 7, and 9).

•Solid content: determined through gravimetric analysis to evaluate the concentration of active ingredients in the formulation.

2.4 Equipment

•Rota Dyer Machine: Model: 12 × 100 CC, Quantity: 12 units, Manufacturer: J.K. Electronics. The Rota Dyer Machine conducts dyeing trials under controlled conditions with 12 simultaneous trials, ensuring uniformity in temperature and temperature rise rate across all samples. The machine features specialized temperature control mechanisms and digital indicators for precise thermal management.

•Infrared Dyeing Machine: Quantity: 24 units, Manufacturer: J.K. Electronics. This machine utilizes infrared radiation to heat and dye textile samples, offering energy efficiency and uniform dyeing with 24 simultaneous trials for accurate and reproducible results.

•Spectrophotometer: Model: X-Rite CI7X Series. This instrument measures the whiteness index of desized fabrics based on CIE Whiteness Index standards, using a D65 light source and 10° standard observer configuration for reliable visual ratings of white and near-white textile surfaces.

2.5 Textile Scouring Performance Evaluation

•Scouring Process for Cotton Hosiery Fabric: Cotton greige hosiery fabric samples (5.0 g) were cut and weighed before treatment. MES solutions were prepared at 2.0% and 5.0% concentrations by weight of fabric,



with conventional dioctyl sodium sulphosuccinate (Zywet OTI) as a comparison. Scouring conditions included 98°C temperature, 60 minutes duration, 1:10 material-to-liquor ratio, 1.5% caustic flakes, 2.5% hydrogen peroxide, and 0.5% peroxide stabilizer. Fabric samples were processed in a Rota dyeing machine, followed by thorough rinsing with tap water, hot washing at 95°C, and air-drying at room temperature.

•Scouring Process for Wool Fibers: Greasy wool fibers (10 g) were weighed for application. MES solutions were prepared at 2.0% and 5.0% concentrations with Alpha Olefin Sulphonate as reference. Scouring conditions included 60°C temperature, 45 minutes duration, 1:10 material-to-liquor ratio, and soda ash to maintain pH 8.5. Samples were processed in a Rota dyeing machine, then rinsed with tap water and air-dried at room temperature.

•Scouring and Stain Removing Process for Polyester Fabric: Stained polyester greige fabric samples (10 g) were cut and weighed. MES solutions were prepared at 1.0% and 2.0% concentrations with Zywet NIS -nonionic wetting agent as a comparison. Scouring conditions included 110°C temperature, 30 minutes duration, 1:10 material-to-liquor ratio, and 0.5% soda ash. Samples were processed in an Infrared dyeing machine, then rinsed with tap water and air-dried at room temperature.

2.6Performance Assessment: The performance assessment included five key tests.

•Absorbency: evaluated using the AATCC 39 method, where water drops at 21±1°C were applied to fabric samples in embroidery hoops from a height of 1 cm, measuring the time until the droplet loses specular reflectivity with five readings averaged per sample.

•Whiteness Index: measured using X-Rite Color Ci7600 spectrophotometer with CIE method using 10-degree observer.

•Weight Loss: testing followed ISO 1383-1977 standard, comparing greige fabric weight before and after scouring.

•Sinking Test: conducted according to JIS 1907, measured the time for scoured specimens to become fully saturated when placed on the water surface.

•Wicking Test: performed using the AATCC 197 method, measured the distance water travels upward

through fabric after 15 minutes with the bottom edge in water contact.

3. Results

3.1 Physical Properties of MES

The synthesized MES surfactant was characterized through various physical and chemical tests to evaluate its performance characteristics. The results are summarized in Table 1, 2 and 3.

Table 1: Physical Properties of the MES

MES Properties	Result
Appearance	Yellowish Clear Liquid
pH of 10%	4.54
Solid Content at 105°C for 2 hours	30%
Surface Tension (0.05%)	35.97 mN/m
Surface Tension (0.1%)	35.21 mN/m
Emulsifying Index	64%
Cloud Point	>100°C
Ionic Nature	Anionic
Specific Gravity	1.002

Table 2 - Wetting Performance by Drave's Test

MES Concentration (g/l)	Time (Seconds)
1.0	300
5.0	53
10.0	37
15.0	21
20.0	10



Table 3 - Foaming by Cylinder Shake Method

MES Concentration (g/l)	Foam Height (ml)
1.0	170
5.0	190
10.0	230
15.0	230

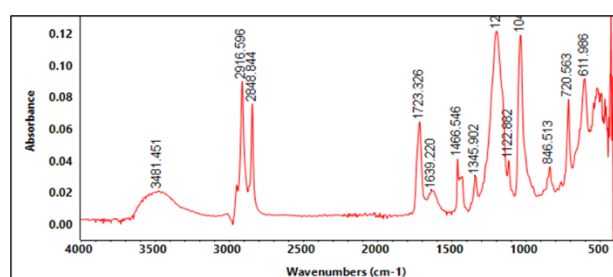


Figure 1 – FTIR of synthesized MES

The Fourier Transform Infrared Spectroscopy (FTIR) analysis of Coconut-Based Methyl Ester Sulfonate (MES) provides valuable insights into its molecular structure and functional groups. The spectrum displays a strong, broad absorption band in the range of 1050–1200

cm^{-1} , which is characteristic of the asymmetric and symmetric stretching vibrations of the sulfonate (SO_3^-) group, confirming the presence of the key sulfonate moiety in MES. A sharp peak near 1730–1750 cm^{-1} corresponds to the ester carbonyl ($\text{C}=\text{O}$) stretching vibration, indicative of the methyl ester linkage derived from coconut oil. Additionally, the aliphatic hydrocarbon chain of the molecule is evidenced by symmetric and asymmetric C-H stretching vibrations observed at 2850–2950 cm^{-1} . A broad peak around 3200–3400 cm^{-1} . Further confirmation of the sulfonate headgroup is supported by smaller peaks near 700–800 cm^{-1} and 1200–1300 cm^{-1} , which are associated with bending and stretching modes of the sulfonate functional group.

The MES surfactant exhibited excellent surface activity with low surface tension values (35.97 mN/m at 0.05% concentration), indicating good wetting properties. The pH of 4.54 suggests mild acidity, which is suitable for textile applications. The emulsifying index of 64% demonstrates good emulsification capability.

3.2 Scouring Results of Greige Cotton Hosiery Fabric

The scouring performance of MES was evaluated on greige cotton hosiery fabric and compared against commercial anionic wetting agent Zywet OTL. The results are presented in Table 4.

Table 4: Comparative scouring performance of MES and Zywet OTL on Cotton Hosiery

Test	MES-2.0%	MES-5.0%	Zywet OTI-2.0%	Zywet OTI-5.0%
Drop Test (Sec)	12	2	13	3
Sinking Test (sec)	22	5	21	3
Capillary Rise (cm)	2.4	3.5	1.9	3.4
Contact Angle	42.8°	36.5°	41.7°	38.6°
Whiteness Index	67.14	68.48	66.09	67.84
Weight Loss (%)	3.44	3.64	3.47	3.57

The results demonstrate that MES exhibits comparable performance to the commercial surfactant Zywet OTI. At 5.0% concentration, MES showed superior capillary rise (3.5 cm vs 3.4 cm) and slightly better whiteness index

(68.48 vs 67.84), indicating effective removal of natural impurities and improved fabric wettability.



3.3 Scouring of Greasy Wool Fibers

The performance of MES on wool scouring was evaluated and compared with Alpha olephin sulphonate (AOS). The results are shown in Table 5. The wool scouring results indicate that MES at 5.0% concentration achieved superior performance with higher weight loss (15.8% vs 14.2%), better cleaning action, and lower

yellowness index (14.6 vs 16.8) compared to AOS Liquid.

3.4 Scouring of Stained Polyester fabric

The performance of MES on stained Polyester was evaluated and compared with the Nonionic commercial scouring agent Zywet NIS Liquid. The results are shown in Table 6

Table 5: Comparative Performance of MES and AOS on Wool Scouring

Test	MES-2.0%	MES-5.0%	AOS -2.0%	AOS -5.0%
Weight Loss (%)	12.5	15.8	11.9	14.2
Cleaning Action (Visual assessment)	Good	Excellent	Good	Very Good
Yellowness Index	18.2	14.6	19.5	16.8
Residual Grease (%)	2.1	1.3	2.4	1.8

Table 6: Comparative Performance of MES and Zywet NIS on polyester fabric.

Test Parameter	MES-1.0%	MES-2.0%	Zywet NIS -1.0%	Zywet NIS -2.0%
Surface Cleanliness Visual Observation	70 %	90%	73%	95%
Absorbency	18 sec	8 sec	21 sec	5.0 sec
Weight loss	1.4%	1.8%	1.45%	1.9%
Whitness of the fabric	87.54	88.54	86.078	87.68

4. Discussion

The systematic investigation into the synthesis and application of methyl ester sulfonate (MES) derived from coconut fatty acid distillate (CFAD) demonstrates its significant potential as a sustainable and high-performance alternative to conventional petroleum-based surfactants in textile scouring processes. The successful synthesis of MES from CFAD via acid-catalyzed esterification followed by sulfonation is a crucial step towards valorizing agricultural waste and reducing reliance on fossil resources. The FTIR analysis

confirmed the presence of characteristic sulfonate (SO_3^-) and ester carbonyl ($\text{C}=\text{O}$) groups, validating the desired chemical structure of MES. The broad peak around $3200\text{-}3400\text{ cm}^{-1}$ in the FTIR spectrum, while noted in the provided text, typically corresponds to O-H stretching vibrations, often indicative of residual moisture or hydroxyl groups in the molecule. Further clarity on its specific origin in this context would strengthen the interpretation. The physical properties of the synthesized MES, as summarized in Table 1, highlight its efficacy as a



surfactant. The low surface tension values (35.97 mN/m at 0.05% and 35.21 mN/m at 0.1% concentration) are indicative of excellent wetting properties, which are fundamental for effective scouring. A lower surface tension allows the scouring solution to penetrate textile fibers more efficiently, leading to better removal of impurities. The emulsifying index of 64% is also noteworthy, demonstrating the MES's strong ability to emulsify oils and greases, a critical function in textile scouring. The mild acidity (pH 4.54) of the MES solution is generally suitable for various textile applications, potentially reducing the need for extensive pH adjustment compared to highly alkaline or acidic conventional alternatives. The Drave's Test results (Table 2) further support the excellent wetting performance, showing a significant decrease in sinking time with increasing MES concentration, from 300 seconds at 1.0 g/l to just 10 seconds at 20.0 g/l. Similarly, the foaming behavior (Table 3) indicates good foam height and stability, which are desirable characteristics for many scouring operations as foam can aid in the suspension and removal of impurities.

The core of this study lies in the practical application of CFAD-based MES across different textile substrates: cotton hosiery fabric, greasy wool fibers, and stained polyester fabric. In each case, MES was compared against commercially available surfactants, providing a robust benchmark for its performance.

Cotton Hosiery Fabric Scouring: Table 4 demonstrates that MES performs comparably to, and in some aspects, even surpasses the commercial anionic wetting agent Zywet OTI. At a 5.0% concentration, MES achieved a superior capillary rise (3.5 cm vs 3.4 cm for Zywet OTI), indicating enhanced wicking action and better penetration into the fabric structure. This is crucial for efficient removal of impurities and for subsequent dyeing processes. The whiteness index for MES at 5.0% (68.48) was also slightly higher than that of Zywet OTI (67.84), suggesting more effective removal of natural colorants and improved fabric appearance. Both surfactants showed similar weight loss percentages, indicating comparable efficiency in removing natural impurities. The drop test and sinking test results also demonstrate excellent wettability and absorbency with MES, comparable to Zywet OTI, especially at higher concentrations.

Wool Fiber Scouring: For greasy wool fibers (Table 5), MES demonstrated superior grease removal compared to Alpha Olefin Sulphonate (AOS). At 5.0% concentration, MES resulted in a higher weight loss (15.8% vs 14.2% for AOS), which directly correlates to more effective removal of lanolin and other natural greases. This is visually supported by the "Excellent" cleaning action for MES at 5.0% compared to "Very Good" for AOS. Furthermore, MES contributed to a lower yellowness index (14.6 vs 16.8 for AOS), indicating better preservation of the natural whiteness of the wool fibers and reduced yellowing caused by impurities or the scouring process itself. The residual grease percentage was also lower with MES, confirming its enhanced cleaning efficacy.

Stained Polyester Fabric Scouring: While Zywet NIS (a non-ionic wetting agent) showed slightly better performance in terms of surface cleanliness (95% vs 90% for MES at 2.0%) and absorbency (5.0 sec vs 8 sec for MES at 2.0%), MES still delivered highly effective results (Table 6). The whiteness of the fabric was notably better with MES at both concentrations (87.54% at 1.0% and 88.54% at 2.0%) compared to Zywet NIS (86.078% at 1.0% and 87.68% at 2.0%), demonstrating its potential for stain removal and brightening effects on synthetic fabrics. The weight loss percentages were comparable, indicating similar effectiveness in removing sizing agents and other processing impurities. The minor difference in surface cleanliness and absorbency might be attributed to the specific characteristics of the non-ionic surfactant used for comparison, as non-ionic surfactants are often preferred for synthetic fibers due to their effectiveness in removing oily stains and their compatibility with various dyeing systems. However, the overall performance of MES on polyester is still very promising, especially considering its bio-based origin.

5. Conclusion

- This study successfully demonstrated the synthesis of methyl ester sulfonate (MES) from coconut fatty acid distillate (CFAD) and comprehensively evaluated its performance as an eco-friendly textile scouring agent.
- The synthesized MES exhibited excellent surface-active properties, including low surface tension, high emulsifying capacity, and good foaming characteristics, making it highly suitable for wet processing applications.



•Performance evaluations across diverse textile substrates revealed that CFAD-based MES is a highly promising sustainable alternative to conventional petroleum-based surfactants. It achieved comparable or superior results to commercial benchmarks in key performance indicators such as fabric wettability (capillary rise, drop test, sinking test), impurity removal (weight loss, visual assessment), and fabric appearance (whiteness index, yellowness index).

•MES demonstrated superior capillary rise and whiteness index on cotton, enhanced grease removal and reduced yellowness on wool, and comparable overall cleaning efficacy with improved whiteness on polyester.

•The utilization of CFAD, a renewable agricultural byproduct, for MES synthesis aligns perfectly with green chemistry principles and the broader goals of sustainable textile processing.

•This bio-based surfactant offers significant environmental advantages, including enhanced biodegradability and reduced dependence on fossil fuel resources.

•The findings of this research strongly support the industrial adoption of CFAD-based MES as a viable, high-performance, and environmentally responsible solution for textile scouring, contributing significantly to a more sustainable textile industry.

Acknowledgement

The authors gratefully acknowledge the invaluable contributions of all individuals and organizations that facilitated the successful completion of this research. Our gratitude is also extended to Rossari Biotech Limited for supplying the commercial textile chemicals, which served as essential benchmarks for comparative performance assessment.

References

1. Textile Exchange. (2023). Preferred Fiber and Materials Market Report 2023. Textile Exchange.
2. Ellen MacArthur Foundation. (2017). A new textiles economy: Redesigning fashion's future. .
3. Kant, R. (2012). Textile dyeing industry environmental hazard. *Natural Science*, 4(1), 22-26.
4. Holkar CR, Jadhav AJ, Pinjari DV, Mahamuni NM, Pandit AB. A critical review on textile wastewater treatments: Possible approaches. *J Environ Manage*. 2016 Nov 1;182:351-366. doi: 10.1016/j.jenvman.2016.07.090. Epub 2016 Aug 3. PMID: 27497312.
5. Anastas, P. T., Warner, J. C. (1998). *Green Chemistry: Theory and Practice*. Oxford University Press.
6. Anastas, P., Zimmerman, J. B. (2003). Design through the 12 principles of green engineering. *Environmental Science & Technology*, 37(5), 94A-101A.
7. Sheldon, R. A. (2012). *Fundamentals of green chemistry: efficiency in reaction design*. *Chemical Society Reviews*, 41(4), 1437-1451.
8. European Chemicals Agency. (2020). *Understanding REACH*. European Chemicals Agency.
9. Geiser, K. (2015). *Chemicals without harm: policies for a sustainable world*. MIT Press.
10. Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11-32.
11. Stahel, W. R. (2016). The circular economy. *Nature*, 531(7595), 435-438.
12. Gunawan, E. R., Basri, M., Rahman, M. B. A., Salleh, A. B., & Rahman, R. N. Z. A. (2005). Study on response surface methodology (RSM) of lipase-catalyzed synthesis of palm-based wax ester. *Enzyme and Microbial Technology*, 37(7), 739-744.
13. Demirbas, A. (2009). Progress and recent trends in biodiesel fuels. *Energy Conversion and Management*, 50(1), 14-34.
14. Hossain, Md Alamgir & Chowdhury, Shabab & Rekhu, Yamin & Faraz, Khandakar & Islam, Monzur. (2012). *Biodiesel from Coconut Oil: A Renewable Alternative Fuel for Diesel Engine*. World Academy of Science, Engineering and Technology. 68. 1289.
15. Satsuki, T. (1991). α -Sulfonated fatty acid esters. *Journal of the American Oil Chemists' Society*, 68(11), 827-832.
16. Matthijs, E., Holt, M. S., Kiewiet, A., & Rijs, G. B. (1999). Environmental monitoring for linear alkylbenzene sulfonate, alcohol ethoxylate, alcohol ethoxy sulfate, alcohol sulfate, and soap. *Environmental Toxicology and Chemistry*, 18(11), 2634-2644.



17. Behler, A., Biermann, M., Hill, K., Raths, H. C., Schwuger, M. J., & Tesmann, H. (2000). α -Sulfonated fatty acid methyl esters—a new class of anionic surfactants. *Tenside Surfactants Detergents*, 37(6), 374-378.
18. Modler, R. F., Willingham, T. W., & Tazuma, J. J. (1979). Biodegradation of alpha-sulfonated fatty acid methyl esters. *Journal of the American Oil Chemists' Society*, 56(10), 789-792.
19. Willing, A. (2001). Oleochemical raw materials and their utilization. *Fett/Lipid*, 103(4), 192-198.
20. Yamane, T., Watanabe, Y., Toyama, S., & Tan, I. S. (2002). Enzymatic synthesis of α -sulfonated fatty acid methyl esters from fats and oils. *Biotechnology and Bioengineering*, 78(3), 339-345.
21. Karmakar, S. R. (1999). *Chemical Technology in the Pre-treatment Processes of Textiles*. Elsevier Science.
22. Hardin, I. R., & Wilson, S. S. (1999). Optical brightening agents and textile white appearance. *Textile Research Journal*, 69(12), 907-918.
23. Choudhury, A. K. R. (2006). *Textile preparation and dyeing*. Science Publishers.
24. Rowe, T. (2005). Sustainable textile scouring. *Textile Research Journal*, 75(7), 520-526.
25. Rosen, M. J., & Kunjappu, J. T. (2012). *Surfactants and interfacial phenomena*. John Wiley & Sons.
26. Holmberg, K., Jönsson, B., Kronberg, B., & Lindman, B. (2002). *Surfactants and polymers in aqueous solution*. John Wiley & Sons.
27. Rajesh, K., Devan, P. and Bharth Sai Kumar, G. "Parametric Optimization and Biodiesel Production from Coconut Fatty Acid Distillate", *Iranian Journal of Chemistry and Chemical Engineering*, 40, 1, 2021, 343-355. doi: 10.30492/ijcce.2020.39119
28. Yusuff, A., Porwal, J., Bhonsle, A., Rawat, N., Atray, N. (2021). Valorization of used cooking oil as a source of anionic surfactant fatty acid methyl ester sulfonate: *Biomass Conversion and Biorefinery*. 13. 10.1007/s13399-021-01663-y.
29. Wibowo A., Yoshi L, Handayani A, Joelianingsil. (2021) Synthesis of polymeric surfactant from palm oil methyl ester for enhanced oil recovery application. *Colloid Polym Sci* 299:81–92