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SYNTHESIS AND SURFACTANT PROPERTIES OF CARBOHYDRATE-BASED CATIONIC SURFACTANT

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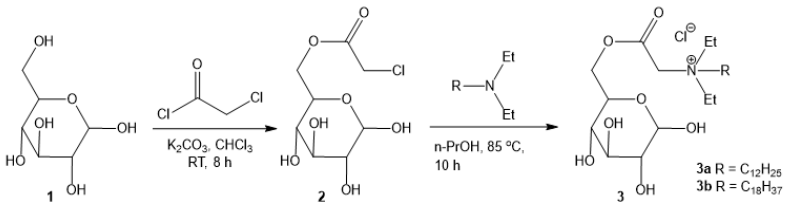
A novel carbohydrate-based cationic surfactant was synthesized from glucose, chloroacetyl chloride, and fatty alcohol through a two-step process. The structure of the product was confirmed by spectral and physicochemical analyses. The synthesized quaternary ammonium compound was evaluated for surface-active properties such as foaming stability, softness, and antibacterial activity, as well as compatibility with sodium dodecyl sulfate (SDS). The surfactant exhibited good foaming stability, satisfactory surface and softening performance, and a synergistic effect with SDS. It demonstrated potential for use in shampoo, fabric softener, and liquid soap formulations without adverse effects on aquatic environments. Furthermore, the surfactant derived from chloroacetyl chloride showed enhanced antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. Owing to its carbohydrate ester-based structure, the compound is considered to be environmentally benign.



INTRODUCTION

Surfactants are indispensable functional materials widely used in detergents, coatings, pharmaceuticals, agrochemicals, personal care products, and enhanced oil recovery processes.[1] Their ability to adsorb at interfaces and reduce surface and interfacial tension enables emulsification, wetting, dispersion, and detergency. Among the different classes, cationic surfactants occupy a distinctive position due to their strong adsorption on negatively charged surfaces and their inherent antimicrobial properties, making them particularly valuable in fabric softeners, disinfectants, corrosion inhibitors, and conditioning formulations.[2]

In recent years, growing environmental awareness and regulatory pressure have intensified the search for sustainable surfactants derived from renewable resources. Conventional petrochemical-based cationic surfactants often raise concerns related to biodegradability, toxicity, and environmental persistence.[3] As a result, carbohydrate derived surfactants particularly those synthesized from glucose have emerged as promising alternatives owing to their renewable origin, structural versatility, and

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favourable environmental profile.[4] Glucose is especially attractive as a starting material because it is low cost, abundantly available from biomass and possesses multiple hydroxyl groups that allow structural modification and tunable amphiphilic architectures.

Esterquat surfactants derived from fatty acids or fatty alcohols represent an important class of biodegradable cationic surfactants.[5] Industrial demand continues to grow for surfactants that exhibit lower critical micelle concentration (CMC), efficient surface tension reduction, improved wettability, enhanced foaming performance, stable emulsification behaviour, and controlled antimicrobial activity.[6] Howeverachieving such properties simultaneously through simple and cost-effective synthetic routes remains a challenge.

The motivation of the present study arises from the need to design glucose-based cationic esterquats through a streamlined synthetic pathway that minimizes reaction steps while maintaining structural flexibility. By systematically varying the hydrophobic chain length of the fatty alcohol and modifying the alkylating agent, it becomes possible to tailor the balance between hydrophilicity and hydrophobicity, thereby optimizing surface-active and biological properties.[7] Such structural tuning is essential for correlating molecular architecture with physicochemical behaviour and antibacterial performance.

Renewable feedstock such as D-glucose, sucrose, lactose, and fatty acids offer additional advantages beyond sustainability, including low cost, ease of purification, and strong compatibility with green chemistry.[8] Importantly, glucose-based cationic surfactants are generally associated with rapid biodegradability, reduced bioaccumulation potential, and improved skin compatibility compared to multiple conventional quaternary ammonium compounds.[9] Nevertheless, it must be emphasized that natural origin does not automatically ensure non-toxicity; therefore, systematic evaluation of performance and antibacterial activity is essential.

Esterquat salts are well recognized for their excellent fabric-softening efficiency, antistatic properties, and antimicrobial activity.[10] Glucose-derived quaternary ammonium surfactants are attracting increasing attention as environmentally friendly, multifunctional agents for hair conditioning, microbial control, and fabric softening, owing to their wide-range of pH stability and sustainable, biocompatible profile.

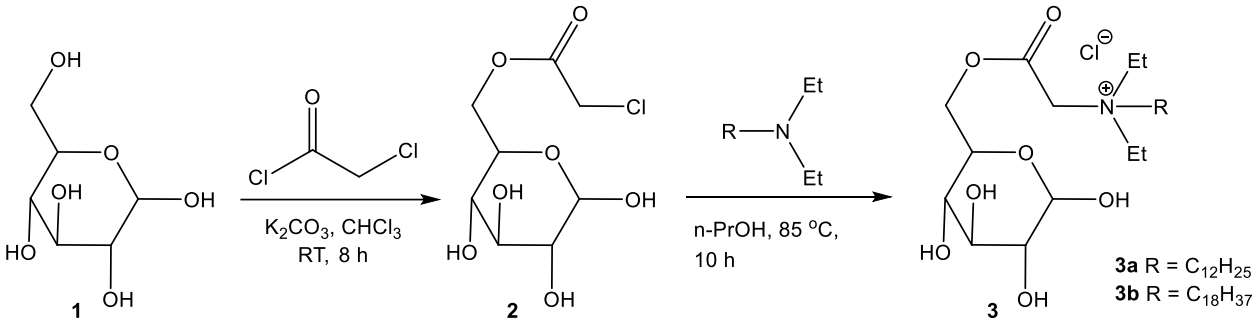

Fig. 1 – Synthesis of glucose-based quaternary ammonium salts.

In this context, the present research work reports a synthesis of carbohydrate-based esterquat cationic surfactants derived from glucose through a two-step reaction pathway (Fig. 1). The synthesized compounds were systematically evaluated for surface-active properties including CMC, surface tension reduction, foaming, and wettability as well as antibacterial activity. Furthermore, their interaction with the anionic surfactant sodium dodecyl sulfate (SDS) was investigated to assess synergistic effects in mixed systems. This study aims to establish a structure property relationship by elucidating the influence of fatty alcohol chain length and alkylating agent on surface behaviour and antimicrobial efficacy, thereby contributing to the development of ecofriendly, renewable, and performance-optimized esterquat surfactants suitable for future industrial applications.

EXPERIMENTAL

1. Materials

α-D-Glucose (≥99%, analytical grade), lauryl alcohol (dodecanol, ≥99%), stearyl alcohol (octadecanol, ≥98%), and chloroacetyl chloride (≥98%, moisture-sensitive reagent) were purchased

from Thomas Baker Pvt. Ltd. (Mumbai, India). Anhydrous potassium carbonate (K_2CO_3, ≥99%) and sodium sulfate (Na_2SO_4, ≥99%, drying agent grade) were also obtained from the same supplier.Toluene (anhydrous, 99.5%), diethyl ether (≥99.5%, peroxide-forming solvent), n-hexane (≥95%), chloroform (stabilized, ≥99%), and ethyl acetate (≥99.5%) were procured from Sigma-Aldrich Pvt. Ltd. (India).

All reagents were used as received without further purification unless otherwise stated. Deionized water was used throughout the experiments.100% Cotton plain woven fabric ($60^s/60^s$) of GSM 120 and 100% Polyester plain woven fabric ($40^s/40^s$) of GSM 80 was purchased from Piyush Syndicate, Mumbai, India.

2. Methods

2.1. Preparation of 6-O-(2-Chloroacetyl)-D-Glucose (2)

α-D-Glucose (5.00 g, 27.75 mmol, 1.0 equiv.) and anhydrous potassium carbonate (7.66 g, 55.5 mmol, 2.0 equiv.) were suspended in dry chloroform (30 mL) in a 100 mL oven-dried round-bottom flask equipped with a magnetic stirrer and drying tube. The reaction mixture was stirred under nitrogen atmosphere at room temperature (25 ± 2 °C). In a separate flask, 2-chloroacetyl chloride (3.48 g, 2.70 mL, 30.5 mmol, 1.1 equiv.) was dissolved in dry chloroform (10 mL) and added dropwise to the stirred suspension over 30 min under vigorous stirring. The reaction was allowed to proceed for 8 h at room temperature. The progress of the reaction was monitored by thin-layer chromatography (TLC) using hexane:ethyl acetate (7:3 v/v) as the mobile phase.After completion, the reaction mixture was filtered to remove inorganic salts (KCl and excess K_2CO_4). The filtrate was washed successively with distilled water and brine solution, dried over anhydrous sodium sulfate, filtered, and concentrated under reduced pressure.The crude product was purified by silica gel column chromatography using hexane:ethyl acetate (8:2 v/v) as eluent. Final purification was achieved by recrystallization from ethyl acetate to afford 6-O-(2-chloroacetyl)-D-glucose (2) as an off-white solid. The yield obtained was around 80–85% having a physical appearance of Off-White crystalline solid particles (see Table 2 and Fig. 2).

2.2. Synthesis of Glycosurfactants (3a, 3b)

6-O-(2-Chloroacetyl)-D-glucose (2) (2.55 g, 10.0 mmol, 1.0 equiv.) was dissolved in *n*-propyl alcohol/deionized water (30 mL, 1:2 v/v). The corresponding fatty tertiary amine (12 mmol, 1.2 equiv.) was added dropwise. The reaction mixture was heated at 85–90 °C for 10 h with continuous stirring. Progress of the reaction was monitored by TLC (chloroform:methanol, 8:2 v/v).After completion, solvent was removed under reduced pressure. The crude product was washed with cold diethyl ether, purified by silica gel column chromatography (chloroform:methanol, 9:1 v/v), and recrystallized from petroleum ether/ethyl acetate (7:3 v/v).Compounds 3a: N,N-diethyl-N-dodecylamine (3.10 g, 12 and 3b: N,N-diethyl-N-octadecylamine (3.95 g, 12 mmol) were obtained. The yield obtained for compounds 3a and 3b were nearly 78–80% and 75–78% respectively.

Table 1

Synthesis of 6-O-(2-Chloroacetyl)-D-Glucose (2) and Glycosurfactants (3a–3b)

Step	Reaction	Reactants / Reagents	Conditions	Product	Yield (%)
1	Preparation of 6-O-(2-Chloroacetyl)-D-Glucose (2)	α-D-Glucose, K_2CO_3, 2-Chloroacetyl chloride	Room temperature, 8 h	Compound (2)	80–85
2	Synthesis of Glycosurfactant (3a)	Compound (2), Tertiary amine (from fatty alcohol &diethylamine)	85–90 °C, 10 h	Compound (3a)	75–80
3	Synthesis of Glycosurfactant (3b)	Compound (2), Tertiary amine (from fatty alcohol &diethylamine)	85–90 °C, 10 h	Compound (3b)	75–80

3. Characterization of esterquat and Esteramide Quat

3.1. FT-IR spectroscopy

FT-IR spectra and cationic content analyses of the synthesized cationic surfactants were performed to confirm their structural features. The spectra were recorded on a *Miracle 10 DRS* plate accessory, with each sample analyzed over 30 scans. The characteristic absorption bands corresponding to ester and amide functionalities were identified, confirming successful synthesis of the desired compounds. The spectral data are summarized in Table 2.

Table 2

FT-IR spectrum

Group	6-O-(2-Chloroacetyl)-D-Glucose [cm^{-1}]	Glyco-surfactants:3a [cm^{-1}]	Glyco-surfactants:3b [cm^{-1}]
O-H stretching	3452.71	3332.99	3317.56
O-H Deformation	1008.77	1160.85	1135.99
C=O/ Amide	1737.86/1649.14	1734.01	1734.69
C-O	1163.86	1100.5	1101.79
CH_2	2857.80–2950.38	2839.22–2972.31	2988.16–2850.79
Quaternary N^+		1465.33	1456.90

3.2. Determination of Surface tension and CMC

The surface tensions of aqueous solutions of 3a: SDS and 3b:SDS mixtures were measured using a *Krüss Tensiometer K-100* (Krüss GmbH, Germany) at 25 °C by the plate method. The glucose-based cationic surfactants exhibited excellent solubility in water at 25 °C. The critical micelle concentration (CMC) values and corresponding surface tensions at CMC (γCMC) are presented in Tables 3 and 4. The CMC represents the concentration at which surfactant molecules aggregate into micelles. The esterquat derivatives exhibited notably low CMC values and were able to reduce surface tension below 35 mN/m at a concentration of 0.1 g/L.[11]

Table 3

Surface tension and CMC of 3a: SDS mixed system

	3a:SDS				
	1.0	0.1:1	0.3:1	0.5:1	0:1
CMC [mmol/L]	0.63	0.057	0.474	0.122	0.072
CMC [mN/m]	25.74	22.68	22.78	23.60	28.55

Table 4

Surface tension and CMC of 3b: SDS mixed system

	3b:SDS				
	1.0	0.1:1	0.3:1	0.5:1	0:1
CMC [mmol/L]	0.002	0.152	1.364	0.122	0.072
CMC [mN/m]	25	24.73	24.86	24.67	28.55

3.3. Foamability

Foaming depends on the stability of the liquid–gas interface. The foaming properties were evaluated by measuring the maximum foam volume generated in a stoppered cylinder.[12] A 20 mL aliquot of 1 % (w/w) surfactant solution was transferred to a 100 mL stoppered cylinder and shaken 50 times. Foam volumes were recorded after 30 s, 3 min, and 5 min. The results are presented in Table 5, while the foaming capacities of the 3a:SDS and 3b:SDS mixed systems are summarized in Table 6**.**

Table 5

Foam stability of quaternary ammonium salts

Surfactant	Volume of foam /ml after		
	30 sec	3 min	5 min
CTAB	70	68	60
3a	55	50	49
3b	48	45	40
APG	80	80	80

Table 6

Foaming power of 3a:SDS and 3b:SDS mixed systems

Surfactant mixture	Time	Surfactant mixture ratio				
		0:1	0.1:1	0.3:1	0.5:1	1:0
3a-SDS	30 Sec	25	95	100	110	100
	3 min	24	90	95	110	80
	5 min	23	90	92	90	60
3b:SDS	30 Sec	25	70	80	89	100
	3 min	24	69	77	78	80
	5 min	24	60	61	64	68

3.4. Antibacterial activity

Antibacterial activities of the synthesized glucose-based cationic surfactants were evaluated against Staphylococcus aureus (Gram-positive) and Escherichia coli (Gram-negative). An inoculum (1 mL) from a nutrient broth containing approximately 10^9 CFU mL^{-1} of each test organism was spread on agar plates in triplicate. Wells (4 mm diameter) were cut using a stainless-steel borer – one filled with water (blank) and the remaining with 70 µL of the surfactant sample. Plates were incubated at 37 °C for 24 h.[13] Average inhibition zone diameters were measured, and blank values subtracted to yield the effective inhibition zones. The antibacterial results are summarized in Table 7. The stability of the mixed aqueous systems of 3a and 3b with SDS was also determined, as shown in Table 8.[14,15]

Table 7

Results of antibacterial activity of glucose-based cationic surfactant (the values of inhibition zone are mentioned on the 'mm' scale)

Surfactant	*E. coli*	*S. aureus*
	Inhibition zone(mm)	**Inhibition zone(mm)**
3a	12.5	7.5
3b	20	8
CTAB	9	7

Table 8

Antibacterial activity 3a: SDS and 3b:SDS mixed systems (the values of inhibition zone are mentioned on the 'mm' scale)

Surfactant	*E. coli*	*S. aureus*
	Inhibition zone(mm)	**Inhibition zone(mm)**
3a	12.5	7.5
3a:SDS	11.5	7.5
3b	15.1	8
3b:SDS	11.2	9

3.5. Softening

A sensory panel test was conducted to assess the softening performance of the synthesized surfactants based on a standardized "feel" evaluation method.[16] Both untreated and treated fabric samples were provided to trained panellists for comparison. The softening performance for each substrate was expressed as an average score, with higher scores indicating better softness. The results are summarized in Table 9.

Table 9

Comparable result of softening property of 1% aqueous solution of esterquat

Surfactant	100% cotton	100% polyester
3a	++++++	++++
3a:SDS	++++	++
3b	+++++	+++
3b:SDS	+++	+
Kaosoft agl85	++++++	++++

RESULTS AND DISCUSSION

1. FTIR spectroscopy

Various functional groups of the synthesized compounds were confirmed by FT-IR spectroscopy (Table 2; Fig. 2). The broad band around 3233 cm^{-1} corresponds to the –OH stretching vibration of glucose, while the band near 1034 cm^{-1} is due to –OH deformation. The peaks near 1007 cm^{-1} and 1330 cm^{-1} confirm ester formation, and the absorption at 1456 cm^{-1} is attributed to the quaternary nitrogen of the esterquats (3a, 3b).[17]

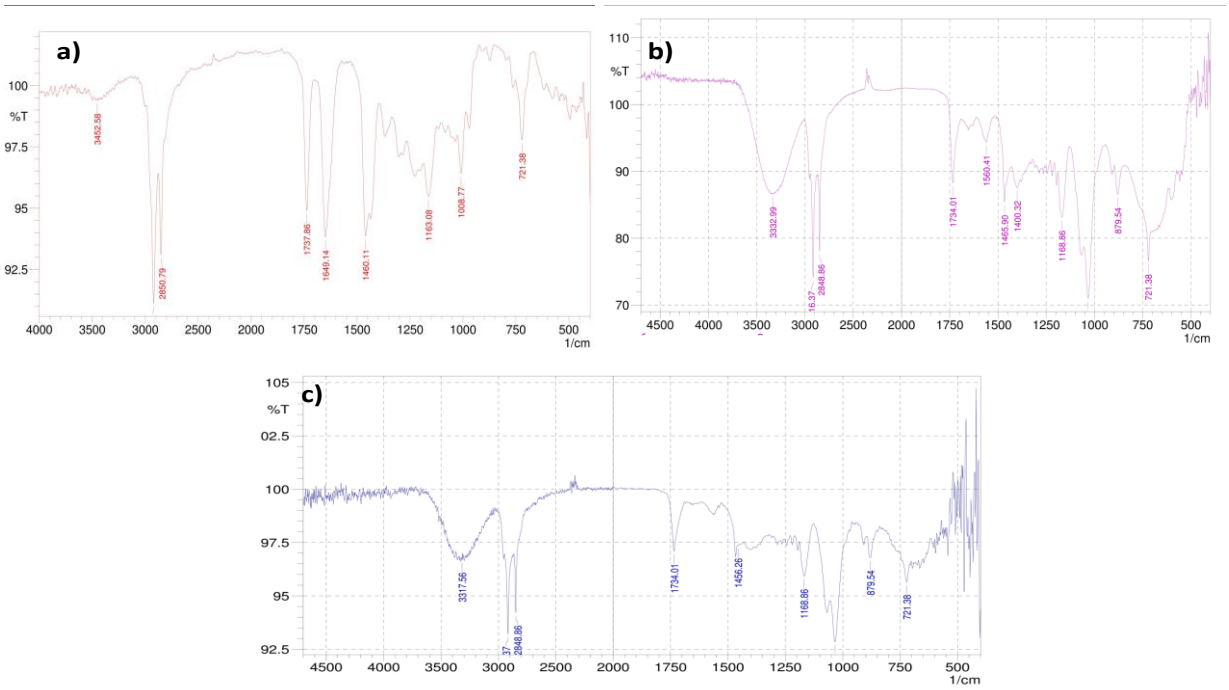

Fig. 2 – FT-IR spectrum of 6-O-(2-Chloroacetyl)-D-Glucose, Glycosurfactant 3a and 3b.

2. Surface active properties

The surface tension of glucose-based quaternary ammonium salts varies with concentration, alkyl chain length, and type of alkylating agent. The CMC values for 3a and 3b were determined to be 0.630 mmol/L and 0.002 mmol/L, respectively. The surface tensions at CMC (γCMC) were 25.74mN/m and 25 mN/m. The decrease in CMC with increasing hydrocarbon chain length reflects enhanced hydrophobic interactions. Tables 3 and 4 show the surface tension and CMC data for mixtures of 3a or 3b with SDS. The CMC of the mixed systems was much lower than that of either individual surfactant, whereas γCMC remained

comparable. This reduction in CMC is attributed to synergistic interactions between the oppositely charged head groups of cationic and anionic surfactants, which reduce electrostatic repulsion and promote micellization.[18]

3. Foamability

Foamability results Table 5 revealed that the cationic surfactant 3b exhibited slightly lower foam stability than 3a. Both 3a and 3b displayed moderate foaming, lower than alkyl polyglucosides (APG) and cetyltrimethylammonium bromide (CTAB). Foam stability improved with increasing hydrocarbon chain length. The order of foamability was APG > CTAB > 3a > 3b. The addition of SDS significantly enhanced foam height and stability due to electrostatic attraction between the cationic and anionic surfactant molecules, indicating a synergistic effect (Table 6, Fig. 3).

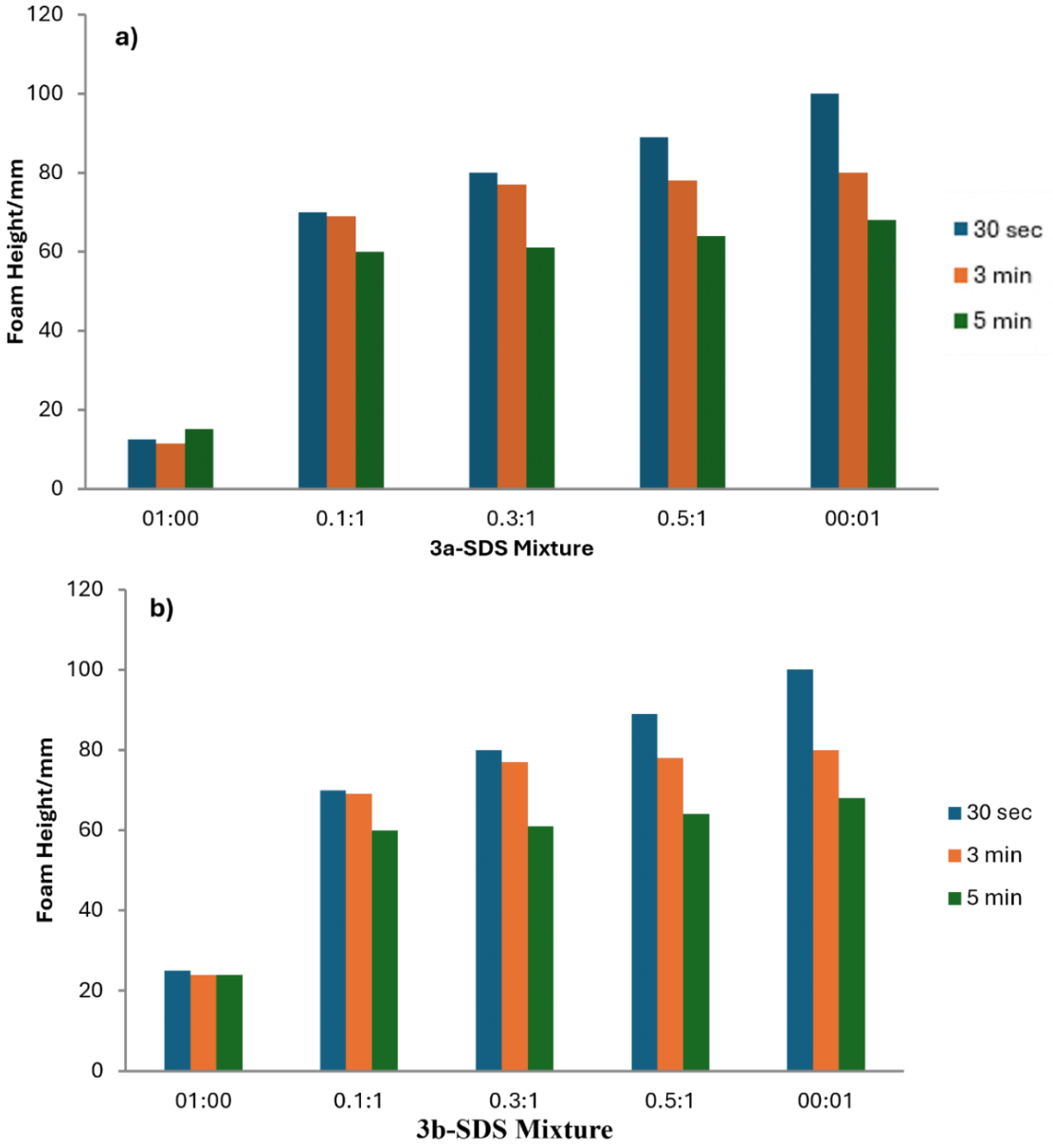

Fig. 3 – Foaming stability of a) 3a:SDS and b) 3b:SDS mixed systems.

4. Antibacterial activity

Esterquats have been widely used as antibacterial agents.[19] CTAB was considered as a reference compound for comparison. This is due to two main reasons: first, its strong efficacy against a broad spectrum of bacterial strains (both Gram-positive and Gram-negative), and second, its wide

applicability in drug formulations, particularly in traditional medicine. The sterilisation effect is attributed to the adsorption and penetration of ester quat molecules onto the microbial surface. The antibacterial activity or bactericidal efficacy depends on several factors, including the hydrophobic chain length, surface activity, type of alkylating agent, dosage, and the structural characteristics of bacterial cell membrane.

In the present research work, the antibacterial activity of the cationic surfactant against *E. coli* and *S. aureus* bacteria was determined. The average rate of bacterio statics of the **3a, 3b**, CTAB against *E. coli* and *S. aureus* is shown in Table 7. It is clearly seen that the **3b** has the highest antibacterial efficiency for *E. coli* as compared to *S. aureus*, but the antibacterial activity of the **3a** and CTAB comparatively were less. This result can be explained as follows: the antibacterial activity of ester quats is determined by the structure, alkylation agent and properties of the molecule, which depends both on the hydrophilic and hydrophobic parts of the molecule, *i.e.*, this activity is relative to hydrophilic-hydrophobic equilibrium (HLB) of the molecule.[20] Results indicated that the overall antibacterial activities on three common bacteria were basically equivalent to that of the control. It is noteworthy that the **3b** cationic surfactant provided the highest activity against *E. coli*, as compared to the other cationic surfactant. Quaternary ammonium surfactant **3b** is the most effective antibacterial agent than the corresponding other surfactant and has more effective spectrum compared to **3a** and CTAB as shown in Table 5 and Fig. 4. The difference in antibacterial activity in both the species is caused by the structure of the microbial cell.[21] The external layer of the outer membrane of Gram-negative bacteria is almost entirely composed of lipopolysaccharide and proteins that restrict the entrance of biocides and amphiphilic compounds are hence more resistant than gram-positive bacteria.[22] Overall, it was observed that the synthesized cationic surfactants exhibited higher antibacterial activity against Gram-negative bacteria than Gram-positive bacteria Table 8.[23]

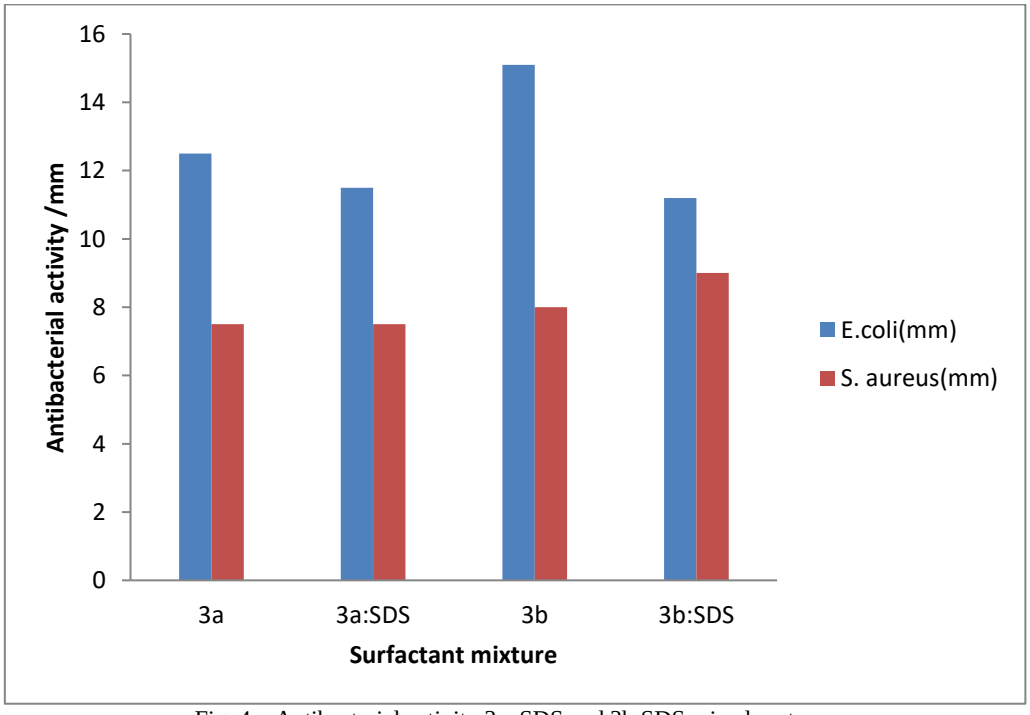

Fig. 4 – Antibacterial activity 3a: SDS and 3b:SDS mixed systems.

5. Softening

Cationic surfactants are widely used as fabric softeners.[24] The softening performance of the synthesized glycol surfactants (3a and 3b) was evaluated on cotton and polyester fabrics and compared with a commercial cationic softener. The results clearly demonstrate that both synthesized compounds exhibited significant fabric softening efficiency, with performance strongly influenced by alkyl chain length and fabric type. Fabric softening is primarily governed by the adsorption of cationic amphiphiles onto negatively charged textile surfaces. Cotton, being a cellulose-based material

rich in hydroxyl groups, develops a net negative surface charge in aqueous media. The synthesized glycol surfactants contain a quaternary ammonium center, which facilitates strong electrostatic attraction towards the cotton surface. Upon adsorption, the hydrophobic alkyl chains orient outward, forming a lubricating monomolecular layer that reduces inter-fiber friction. This molecular lubrication decreases surface roughness, resulting in enhanced softness and smooth handle.

Polyester, in contrast, is a hydrophobic synthetic fiber composed primarily of polyethylene terephthalate. Although it is non-ionic in nature, but softening occurs through hydrophobic interactions between the long alkyl chains of the glycol surfactants and the polyester surface. The adsorption mechanism in this case is dominated by van der Waals forces and hydrophobic affinity rather than electrostatic interaction. Consequently, slightly lower softening efficiency is generally observed for polyester compared to cotton.

The softness of treated fabrics was evaluated using a panel "feel" test, rated on a qualitative scale of one to five (+) symbols from poor to excellent softness. Overall, the synthesized ester-based glycol surfactants demonstrate effective softening performance comparable to conventional cationic softeners while offering potential advantages in terms of biodegradability and sustainable raw material origin. As tabulated in Table 9, the results confirm that molecular architecture specifically alkyl chain length and the presence of a carbohydrate head group play a decisive role in determining softening efficiency and substrate affinity[25].

CONCLUSION

This study reports the synthesis of carbohydrate-based cationic surfactants *via* a straightforward two-step process, followed by a comprehensive evaluation of their physicochemical and functional properties. The resulting glucose-derived esterquats demonstrated excellent surface activity, effectively reducing the surface tension of water from 72 mN/m to a range of 22.68–28.55 mN/m at low concentrations, along with low critical micelle concentration (CMC) values. In addition to their surface-active behavior, the synthesized quaternary ammonium compounds exhibited significant antibacterial activity and stable foaming characteristics. Their performance as textile softeners further highlights their functional versatility, showing promising softening efficiency on fabric materials. Importantly, the ecofriendly nature of these carbohydrate-based surfactants, combined with their multifunctional properties, underscores their potential for sustainable applications. These findings suggest that the developed compounds are strong candidates for use in personal care products, including hair conditioners, body washes, and hand cleansers.

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REFERENCES

1. M. Svensson, "Surfactants Based on Natural Fatty Acids", in "Surfactants from Renewable Resources", Wiley, Chichester, 2010, pp. 1–19.
2. D. O. Shah, D. O., in "Surface Phenomena in Enhanced Oil Recovery", Plenum Press, New York, 1981, pp. 53–72.
3. P. S. Piispanen, S. Byström, M. Svensson, B. Kronberg, I. Blute and T. Norin, *Journal of Surfactants and Detergents*, **2002**, *5*, 345–351.
4. T. Förster, H. Hensen, R. Hofmann and B. Salka, *Parfümerie und Kosmetik*, **1995**, *76*, 763–768.
5. S. Matsumura, K. Imai, S. Yoshikawa, K. Kawada and T. Uchibor, *Journal of the American Oil Chemists' Society*, **1990**, *67*, 996–1001.
6. K. Hill, W. von Rybinski and G. Stoll, "Alkyl Polyglycosides: Technology, Properties, and Applications", John Wiley & Sons, Weinheim, 2008.
7. M. Arya, "Value Addition of Dhaincha (Sesbania aculeata) Fibres through Dyeing with Synthetic and Natural Dyes", *M.Sc. Thesis*, NDRI, Karnal, 2013.
8. A. S. Mohamed and M. Z. Mohamed, *Journal of Surfactants and Detergents*, **2010**, *13*, 159–163.
9. S. Mishra, *Journal of Oleo Science*, **2007**, *56*, 269–276.
10. M. J. Rosen, "Surfactants and Interfacial Phenomena", 3rd edition, John Wiley & Sons, New York, 2004.
11. W. Von Rybinski and K. Hill, *Angewandte Chemie International Edition*, **1998**, *37*, 1328–1345.
12. W. Qiao, Z. Zheng, H. Peng and L. Shi, *Tenside Surfactants Detergents*, **2012**, *49*, 161–166.
13. V. M. Kulkarni, P. D. Gangawane, A. V. Patwardhan and R. V. Adivarekar, *Octa Journal of Environmental Research*, **2014**, *2*, 4.

14. W. Qiao, Z. Zheng, H. Peng and L. Shi, *Tenside Surfactants Detergents*, **2012**, *49*, 161–166.
15. J. T. Wang, W. Wang, F. S. Wang and Z. P. Du, *China Surfactant Deterg. Cosmet*., **2009**, *39*, 162–165.
16. R. R. Egan, *Journal of the American Oil Chemists' Society*, **1978**, *55*, 118–121.
17. D. L. Pavia, G. M. Lampman and G. S. Kriz, "Introduction to Spectroscopy", Thomson Learning, India, 2007.
19. R. S. Hou, "General Physics Experiment", Chengdu University of Science and Technology Press, Chengdu, 1994.
20. J. Pernak and P. Chwała, *European Journal of Medicinal Chemistry*, **2003**, *38*, 1035–1042.
19. V. Cigáneková, J. Kallová, F. Devínsky and I. Lacko, *Folia Microbiologica*, **1989**, ***34***, 202–208.
21. B. Dizman, M. O. Elasri and L. J. Mathias, *Journal of Polymer Science Part A: Polymer Chemistry*, **2006**, *44*, 5965–5973.
22. M. T. Cronin, A. O. Aptula, J. C. Dearden, J. C. Duffy, T. I. Netzeva, H. Patel and G. Schüürmann, *Journal of Chemical Information and Computer Sciences*, **2002**, *42*, 869–878.
23. M. G. Mondal and A. P. Pratap, *Tenside Surfactants Detergents*, **2017**, *54*, 78–84.
24. J. M. Richmond, "Cationic Surfactants", Surfactant Science Series, Vol. 34, Marcel Dekker Inc., New York, 1990.
25. M. G. Mondal and A. P. Pratap, *Journal of Oleo Science*, **2016**, *65*, 663–670.