JSR Publications

Available Online

J. Sci. Res. **18** (1), 187-200 (2026)

JOURNAL OF SCIENTIFIC RESEARCH

www.banglajol.info/index.php/JSR

Eco-Friendly Soap Production: Physicochemical Characterization, Cleansing Performance, and Yield Optimization Using Various Alkali and Lipid Sources

H. Rahman, M. N. Farha, M. A. Hossain[*]

Department of Chemistry, Rajshahi University of Engineering & Technology, Rajshahi-6000

Received 6 June 2025, accepted in final revised form 27 September 2025

Abstract

An eco-friendly approach to soap production was explored using the semi-boiled saponification method with sodium methoxide (CH_3ONa) as an efficient alkali. The performance of CH_3ONa was compared with that of traditional alkalis (NaOH and KOH) in soap making from various vegetable oils (coconut, peanut, palm, olive, castor, and sesame) and blended oils. The soap yield and physicochemical properties, including pH, free alkali, foam stability, cleansing power, and hardness, were measured. Results showed that CH_3ONa constantly produced the highest yields, up to 98 % for the coconut-sesame oil blend and 94 % for peanut oil. The pH of blended oil soaps with CH_3ONa ranged from 9.60 to 10.00, which was closer to the commercial bathing soap (9.00 to 10.00). However, overall soap pH varied from 9.04 to 11.30. Free alkali was absent in most soaps, indicating proper neutralization. Coconut oil and its blends exhibited higher foam stability, cleansing ability, and balanced hardness. These findings suggest that combining CH_3ONa with blended oils in saponification increases yield and optimizes physicochemical properties, providing an effective strategy for sustainable soap production in both industrial and household use.

Keywords: Saponification; Blended oil; Vegetable oil; Lye solution.

doi: https://dx.doi.org/10.3329/jsr.v18i1.82067 J. Sci. Res. **18** (1), 187-200 (2026)

1. Introduction

Utilizing vegetable oils and animal fats as a low-cost raw material for producing biodiesel, detergents and soap, lubricants, and other industrial applications is being increasingly explored [1-3].

[*] *Corresponding author:* anwarruet10@gmail.com

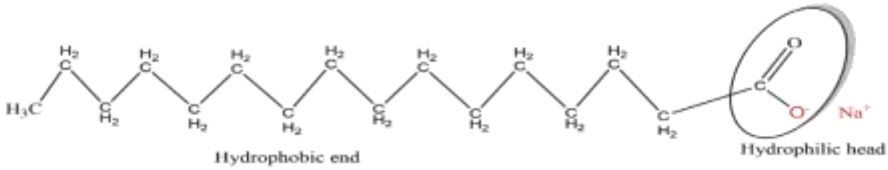


Fig. 1. Structure of a soap molecule.

Soap is a salt of a long-chain fatty acid molecule with a carboxylic acid group at one end, which has an ionic bond with a metal ion and a long nonpolar hydrocarbon chain at the other end. The hydrocarbon chain is insoluble in water but dissolves well in nonpolar substances, allowing soap to interact with both oils and water for effective cleaning.

The structure of soap may be represented as illustrated in Fig. 1 [4]. Traditional soap manufacturing methods frequently depend on alkalis, mainly sodium hydroxide (NaOH) and potassium hydroxide (KOH), and lipid sources such as vegetable oils or animal fats, which serve as the main precursors for soap [5]. The rising requirements for sustainable and environmentally friendly products have led to increased interest in eco-conscious methods of soap production [6]. Therefore, the exploration of efficient and environmentally safer alkalis and optimized lipid blends becomes essential for developing greener alternatives. Among these, sodium methoxide (CH_3ONa) has emerged as a promising alternative alkali due to its high efficiency in transesterification reactions and its higher reactivity [7]. This higher reactivity could offer some potential environmental advantages, such as soap production under milder conditions, higher yield, reduced energy consumption, and byproducts. Collectively, current literature underlines the feasibility and benefits of transitioning to eco-friendly specification processes while identifying challenges related to raw materials variability and scalability [8].

Soap production is a hydrolysis reaction where triglycerides (fats or oils) react with a strong base, forming glycerol and soap [9,10]. Saponification produces soap and glycerol and has gained recent interest in the context of sustainability. The choice of alkali, such as KOH and NaOH, affects the soap's texture and properties. For example, KOH produces soft or liquid soap while NaOH yields hard soap with high cleaning action [11]. Moreover, the varying affinities of potassium and sodium ions for carboxylate anions are what cause this differing effect. This is because the influence the structure and nature of the soap that is produced during the saponification process. The molecular composition of the fats or oils also plays a vital role in shaping the formation [12]. Research highlights that the proportion of saturated to unsaturated fatty acids in oils and fats determines the soap's properties [13], such as hardness and leather quality. For example, higher saturated fatty acid oils such as coconut or palm oil produce harder soaps with rich leather, while oils rich in unsaturated fatty acids such as olive, castor, or canola oil, yield softer soaps that are more moisturizing but slower to leather [14]. Blending these oils can provide complementary fatty acid compositions [15]. This can optimize performance by achieving a suitable balance of cleansing power, foam density, and bar durability.

The combination of blended oils with suitable alkalis could be a promising approach for producing high-yield, good-quality, and environmentally friendly soaps. Therefore, the overall aim of this study was to investigate the effects of different alkalis on various lipid sources to optimize soap yield and boost sustainability. The specific objectives are: to explore how different oils react with various alkalis (NaOH, KOH, and CH_3ONa) to form soap and to evaluate and compare the resulting soaps based on their physicochemical properties.

2. Materials and Methods

2.1. *Raw materials*

Lipid sources: In this study, lipid sources including coconut oil, palm oil, olive oil, castor oil, peanut oil, sesame oil, and blended oils were purchased from the local market, Bangladesh.

Alkalis: Lye solution, as NaOH, KOH, and CH_3ONa was used. NaOH and KOH pellets were purchased from Merck Life Science and Merck Specialities Private Limited (India), and CH_3ONa powder was obtained from Sisco Research Laboratories Private Limited (India).

Fig. 2. Lab desk and some instruments.

Reagent: All necessary reagents were analytical standards. Ethanol, methanol, hydrochloric acid, and phenolphthalein indicator were purchased from VWR(BDH) PROLABO CHEMICALS (France), RCl Labscan Limited (Thailand), Merk (India), and Merck KGaA (Germany) respectively. Moreover, deionized water, salt (NaCl), essential oils, fragrance (optional) were used.
Additional equipment: pH meter (Model: pH54, Brand: Milwaukee, Romania), analytical balance (Model: ABJ220-4NM, Brand: KERN, Germany), beakers, thermometer, and molds were used.

2.2. *Experimental procedure*

2.2.1. *Saponification process*

Saponification was performed using the semi-boiled saponification process, wherein triglycerides were reacted with strong bases such as NaOH, KOH, or CH_3ONa to produce soap and glycerol [16-18]. Each oil (100 g) was mixed with a 30 % lye solution of NaOH, KOH, or CH_3ONa. The mixture was heated to 60-70 °C while stirring continuously. Then, a strong alkali solution was added to initiate the hydrolysis process. The fatty acid reacts with the alkali to produce soap. Stirring ensures complete conversion of soap and a uniform texture. The reaction continued until a thick consistency was achieved. Glycerol separates due to its higher polarity and density. This is often extracted and purified for use in other applications. The soap mixture was poured into molds and left to cure for 24 to 48 hours to harden, then dried before further analysis [19].

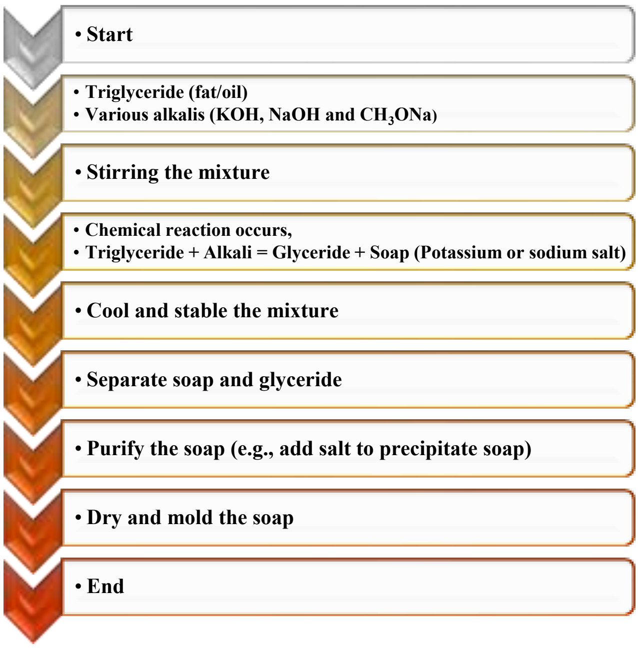
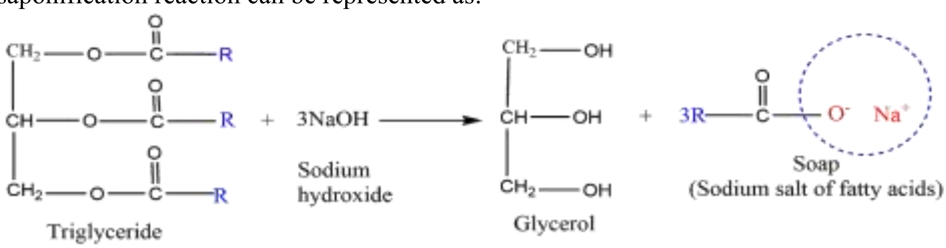


Fig. 3. Flow diagram for soap production.

2.2.2. *Saponification reaction*

Saponification is a base-catalyzed hydrolysis of triglycerides (fats or oils) into glycerol and soap (fatty acid salts) [20]. It is the cornerstone of soap production [21]. The general saponification reaction can be represented as:



Triglyceride + strong base (e.g., NaOH, KOH, or CH_3ONa) = soap + glycerol

3. Cleansing Action of Soap

The role of soap as a cleansing agent for laundering clothes and hygiene items highlights the saponification process in providing its cleaning and emulsifying abilities. Saponification, the reaction at the core of global soap production, involves the conversion of natural fats or oils into alkaline substances [12]. Soap acts as a cleaning agent because its molecules contain both polar (water-attracting) and nonpolar (oil-attracting) sides, allowing it to eliminate grease and dirt that water alone cannot. Saponification occurs between triglycerides (oils or fats) and a lye solution [22,23]. The level of foaming and durability of the emulsion (cleaning ability) from the product of the saponification reactions are two factors to evaluate the optimization process [24]. Saponification occurs between triglycerides (oils or fats) and a lye solution. The level of foaming and durability of the emulsion (cleaning ability) from the product of the saponification reactions are two factors to evaluate the optimization process [25].

When soap or detergent is used in sufficient amounts, the soap molecules group to form a structure called a micelle. In a micelle, the oily tails of the soap molecules point inward, while the water-loving (COO^-) head stays on the outside, touching the water. The greasy strain gate is trapped inside the micelle, where it mixes with the tail of oil. This helps relieve the strain on the fabric. When the grease is removed, the tiny dirt particles attached to it also come off, making the fabric clean [26]. In water, soap or detergent molecules ionize to form an anion and a sodium cation. Therefore, sodium stearate releases an anion and a sodium ion in aqueous solution [27].

Approximately 70 stearate ions can come together to form a colloidal-sized particle. Each stearate ion consists of a long hydrocarbon chain (C-17) with a polar carboxylate group ($-COO^-$) at one end. In a diagram, the hydrophobic tail is often represented by a wavy line, while the polar head is shown as a hollow circle.

$$\mathbf{C_{17}H_{35}COO^- Na^+} \qquad \mathbf{C_{17}H_{35}COO^- + Na^+}$$

Sodium stearate Stearate ion

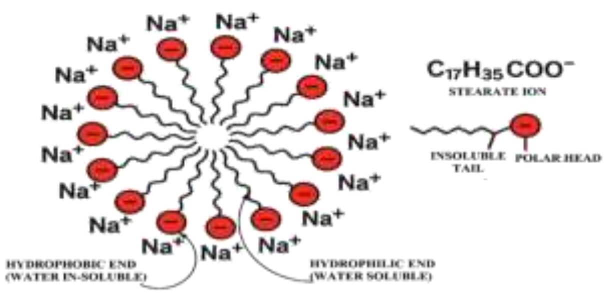


Fig. 4. A soap micelle.

During micelle formation in water, the hydrophobic tails aggregate inward, away from the water, forming the core of the micelle. Meanwhile, the hydrophobic ($-COO^-$) heads reside on the surface, in direct contact with the surrounding water (as illustrated in Fig. 4). The negative charge on the polar head at the surface maintains the micelle particles stable by preventing aggregation through electrostatic repulsion [28].

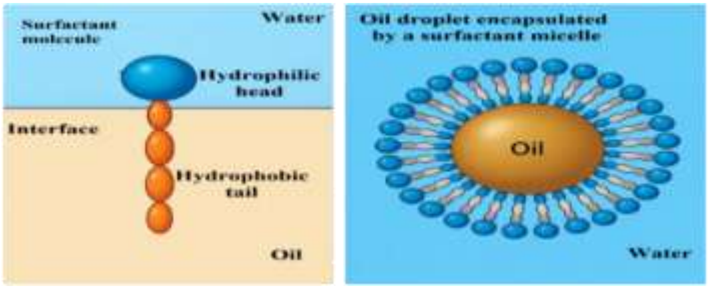


Fig. 5. Illustration of surfactant behavior at an oil-water interface (left), an individual sufficient molecule approaches the interface (right) upon adsorption.

The molecules adopt an orientation in which their hydrophobic tail embeds into the oil phase while the hydrophilic head group remains exposed to the aqueous phase, minimizing interfacial tension [29]. The nonpolar portion of a surfactant is often a hydrocarbon chain, whereas the polar portion (hydrophilic head group) may be ionic (cationic or anionic), non-ionic, or amphoteric [30].

4. Purification, Drying, and Fitting

After saponification, the soap mixer contains contaminants such as excess alkali, glycerol, and unreacted oils. The purification process aims to remove these contaminants to enhance soap quality. In the purification and trying stages of soap production, the washing and fitting process plays a vital role in ensuring product purity and quality [31]. The washing process involves repeated treatment of the soap curd form after salting out with hot water and weak brine to remove residual impurities such as excess alkali, glycerol, and salt. In some cases, a mild acid such as hydrochloric acid was used to neutralize remaining alkaline substances. After washed, the soap undergoes the finishing process, which begins with drying to remove moisture and is followed by a mechanical refining step, such as milling and plodding, and then it is also dried at room temperature for 48 hours. During fitting, the soap can be blended with optional additives, evenly blended with a heavy roller, and extruded into uniform bars, ensuring a smooth texture and high-quality finish suitable for commercial applications.

5. Characterizations

5.1. *Soap yield (%)*

Soap yield is a crucial metric in soap-making, reflecting the efficiency of the saponification process, the chemical reaction where triglycerides (oils) react with an alkali (like sodium hydroxide) to form soap and glycerol. This yield is calculated using the formula [17]:

$$Soap\ yield(\%) = \left(\frac{Mass\ of\ soap}{Mass\ of\ oil}\right) \times 100$$

This formula has been used to calculate the soap yield as a percentage.

5.2. *pH measurement*

The pH of the soap solution was determined using a pH meter. Initially, 150 mg of soap was added to 15 mL of distilled water, and the mixture was gently mixed to prevent foam formation. The mixer was allowed to stand undisturbed for 24 hours to achieve complete dissolution. The pH measurements were then conducted using a properly calibrated digital pH meter (Milwaukee pH54, pen pH meter) [32]. For some modification, 1g of soap was weighed and dissolved in 100 mL of distilled water. The solution was stirred thoroughly until complete dissolution was achieved. The pH meter was calibrated using standard buffer solutions of pH values of 4.00, 7.00, and 10.00. The pH of the soap solution was subsequently determined at 25°C, and the value was recorded after stabilization, allowing for the calculation of the pH.

5.3. *Free alkali test*

Phenolphthalein, a pH indicator that remains colorless in acidic and neutral solutions but pink in basic (alkaline) solutions, typically above pH 8.2. If free alkali is present in the soap, the solution will turn pink upon testing. A small amount of soap (1 g) was dissolved in about 50 mL of methanol. Then it was stirred and heated (<60°C). Then, 3 drops of phenolphthalein indicator were added to the solution. A color change to pink indicates the presence of free alkali, while no color change means the soap is properly neutralized [33].

5.4. *Foam stability test*

About 2 g of soap shavings were placed in a 500 cm^3 measuring cylinder containing 100 cm^3 of distilled water. The mixer was shaken vigorously for approximately 2 minutes to include foam formation. Afterward, the cylinder was left to stand for 10 minutes. The resulting foam stability was classified as high, medium, or low according to the persistence time of the foam produced by each soap [34].

5.5. *Cleansing power*

A small drop of oil was placed on a napkin to make an oily spot. The napkin was then dipped into a soap solution prepared with tap water and gently shaken so the soap could act on the oil. After about 2 minutes, the napkin was taken out, rinsed with water, and observed to see whether the oily stain was removed. This showed the cleaning ability of soap on oily dirt. This procedure was performed with some modifications based on [14].

5.6. *Hardness Test*

Hardness test was measured using physical pressure on soap [14].

6. Results and Discussion

The present study was conducted to produce soap and assess its physicochemical properties. The results of the analysis are presented in Tables 1, 2, 3, and 4.

6.1. *Soap yield analysis*

Soap yield is an important parameter in evaluating the efficiency of the saponification process and overall production quality [2]. Yield depends on various factors, including the type of alkali used, lipid source, reaction temperature, and saponification duration. Using optimized concentrations of NaOH, KOH, and CH_3ONa, along with suitable lipid sources, can significantly improve soap yield, opening exceeding 90 %.

Fig. 6. Yields (soaps) of various oils and alkali.

The influence of different alkalis on soap yield was strongly dependent on oil type. Soap yield (%) for different alkalis and single oils is presented in Table 1. The highest soap yields were observed for peanut, 94 %, and 90 % for coconut, castor, and sesame oils, and 86 % for olive oil. Across these oils, CH_3ONa consistently outperformed KOH and NaOH. However, both NaOH and CH_3ONa yielded 87 % for palm oil. Overall, CH_3ONa demonstrated greater efficiency for sustainable soap production.

Soap yield (%) for different alkalis and blended oils is presented in Table 2. The results showed that the highest yield was 98 % obtained from the coconut oil + sesame oil blend, followed by 92 % from coconut oil + castor oil and coconut oil + palm oil blends. Other blends also reached maximum yields of 90 % and 87 %, respectively. In all cases, CH_3ONa outperformed KOH and NaOH. For single oils, the highest yield was 94% obtained from peanut oil. In comparison, blended oils showed slightly higher or comparable yields, with a maximum yield of 98% from the coconut oil + sesame oil. In both single and blended oils, CH_3ONa delivered higher yields than KOH and NaOH, indicating greater efficiency in soap production. Moreover, the results showed that the blended oils are slightly more effective than individual oils in maximizing soap yield, consistent with previous research [14]. These findings suggest that optimized blending, particularly when combined with CH_3ONa, increases soap yield and supports more efficient production.

Table 1. Soap yield (%) for different alkalis and single oils.

Oil Type	KOH (%)	NaOH (%)	CH_3ONa (%)	Highest Yield (%)	Best Alkali	Best Oil
Coconut oil	80	86	90	90	CH_3ONa	Peanut oil
Palm oil	82	87	87	87	NaOH / CH_3ONa	
Olive oil	34	43	86	86	CH_3ONa	
Peanut oil	89	90	94	94	CH_3ONa	
Castor oil	86	87	90	90	CH_3ONa	
Sesame oil	89	88	90	90	CH_3ONa	

Table 2. Soap yield (%) for different alkalis and blended oils.

Blended Oils	KOH (%)	NaOH (%)	CH_3ONa (%)	Highest Yield (%)	Best Alkali	Best Oil
Coconut oil + Castor oil	90	89	92	92	CH_3ONa	Coconut oil + Sesame oil
Coconut oil + Olive oil	54	89	90	90	CH_3ONa	
Coconut oil + Palm oil	35	90	92	92	CH_3ONa	
Coconut oil + Sesame oil	65	92	98	98	CH_3ONa	
Coconut oil + Peanut oil	37	86	87	87	CH_3ONa	

6.2. *Analysis of physicochemical Properties*

The results of the physicochemical analysis reflecting the properties of the single oil soaps and blended oil soaps are presented in Tables 3 and 4.

6.2.1. *Analysis of pH*

Our results showed that the pH values of all prepared soaps ranged from 9.04 to 11.30 [Tables 3 and 4]. For single oils, coconut and castor soaps exhibited lower pH values of about 9.00 to 9.60, while peanut oil soaps had the highest pH value of around 11.30. Blended oils showed a lower range of pH values between 9.60 and 10.00, with slightly higher readings, 11.00 and 10.90, observed in coconut + olive and coconut + peanut oils. Though CH_3ONa produced slightly higher pH values around 9.60 to 11.20 in single oil soaps, the blended oil soaps showed a lower pH range of about 9.60 to 10.00. The pH of our blended oil soaps was consistent with the previous research [32]. They studied the pH of 64 types of commercial bathing soaps and found that 53 soaps had a pH value within 9 to 10 [32]. However, the pH range indicates the soaps are basic in nature, which can make the soap harsh on the skin. The harshness of soap can be minimized by incorporating excess fat or oil, or by any other super-fattening agent [19].

6.2.2. *Analysis of free alkali test*

The free alkali test was performed to detect the presence or absence of residual alkali in the soap. The presence of free caustic alkali indicates the abrasiveness of a soap [35]. For single-oil soaps, most samples showed no free alkali except for the coconut oil soap with CH_3ONa [Table 3]. Similarly, for blended-oil soaps, free alkali was absent in most samples except for the coconut + olive oil soap prepared with NaOH and CH_3ONa [Table 4]. These results suggest that the soaps were properly neutralized. Excessive free caustic alkali in soap can irritate the skin [35].

6.2.3. *Analysis of foam stability*

Foam stability is an important characteristic of soaps that represents their ability to form and sustain foam effectively. Foam stability of soaps depends on the type of oil and the alkali used. In single oils, coconut oil formed high foam, whereas other oils formed medium and low foam [Table 3]. Blending coconut oil with other oils noticeably improved foam stability, highlighting the role of coconut oils in lather formation [Table 4]. This may be due to the presence of high content of lauric acid in coconut oil, which can provide high solubility and excellent foaming properties in soap products [36]. However, the type of alkali had a smaller effect, as KOH, NaOH, and CH_3ONa formed similar foam behavior. These results indicate that coconut oil and blending it with other oils could play an important role in the foam properties of the soap.

6.2.4. *Analysis of cleansing power*

Our results showed that coconut oil and sesame oil exhibited high cleansing power, while castor oil showed low to medium in single oil soaps, which agrees with the previous results [37]. When coconut oil is combined with the other oils, all blended oil soaps showed high cleansing power. This indicates that the blending maintains strong cleaning efficiency even when castor oil is included. It was reported that lauric acid and myristic acid, both saturated fatty acids, produce soap with a firm lather and higher cleansing power [33]. As coconut oil contains these two fatty acids in relatively high proportions, approximately 46 % lauric acid and 18.5 % myristic acid [38], it can be concluded that coconut oil is primarily responsible for the high cleansing power observed.

6.2.5. *Analysis of hardness*

Generally, soap hardness is influenced by the type of alkali. Sodium hydroxide produces hard soaps, and KOH yields softer and more soluble soaps [12]. Our results were consistent with this trend as NaOH and CH_3ONa produced hard soaps in most oil types, while KOH resulted in soft soaps [Table 3]. In addition, the degree of saturation and chain length of fatty acids affect the soap hardness. Soaps in higher unsaturated fatty acids, such as oleic and linoleic acids, are softer, milder, and more moisturizing, but less foamy [12]. In contrast, long-chain saturated fatty acids such as lauric and myristic acids contribute to form harder soaps with stronger cleansing ability [12]. In agreement with these, our results showed that castor oil-based soap containing higher unsaturated fatty acids was softer, less foamy, and had lower cleansing ability, while coconut oil-based soaps containing higher saturated fatty acids were harder. In blended-oil soaps, similar results were observed with alkali type remaining the dominant factor. However, the addition of harder oils such as coconut slightly improved the overall firmness [Table 4]. Our research confirms that blending can balance these characteristics, enhancing both cleansing efficiency and user feel. This knowledge is essential in industrial and additional soap production to customize formulation for specific skin needs and product types [14].

Table 3. Physicochemical properties of single oils soap.

Oil type	Alkali used	pH	Free alkali test	Hardness/ Texture	Foam stability	Cleansing power
Coconut oil	KOH	9.04	No	Soft	High	High
	NaOH	9.88	No	Hard	High	High
	CH_3ONa	9.97	Yes	Hard	High	High
Palm oil	KOH	9.90	No	Soft	Medium	Medium
	NaOH	10.10	No	Hard	Medium	Medium
	CH_3ONa	10.20	No	Hard	Medium	Medium
Olive oil	KOH	10.50	No	Soft	Medium	Medium
	NaOH	10.15	No	Hard	Medium	High
	CH_3ONa	10.30	No	Hard	Medium	Medium
Peanut oil	KOH	10.00	No	Soft	Medium	Medium
	NaOH	11.30	No	Hard	Medium	Medium
	CH_3ONa	11.20	No	Hard	Medium	Medium
Castor oil	KOH	9.35	No	Soft	Low	Low
	NaOH	9.50	No	Hard	Low	Low
	CH_3ONa	9.60	No	Soft	Low	Medium
Sesame oil	KOH	10.00	No	Soft	High	High
	NaOH	10.03	No	Hard	Medium	High
	CH_3ONa	10.00	No	Hard	High	High

6.3. *Environmental impact*

Over the past 20 years, the traditional process of soap making has evolved into a highly advanced chemical industry [37]. Plant-based vegetable oil soaps are readily biodegradable and do not form any dangerous waste; thus minimize the environmental impact and aquatic toxicity [39]. This study explores eco-friendly soap production as various natural lipid sources, including coconut oil, olive oil, palm oil, sesame oil, castor oil with KOH, NaOH, CH_3ONa were used. It highlights that the choice of alkali affects the texture and performance of soap as well as the environmental impact. Sodium methoxide allows effective saponification under milder conditions and potentially reduces energy consumption. This approach reduces the emissions and chemical waste that providing a cleaner, more responsible alternative to conventional detergent-based cleansing products.

Table 4. Physicochemical properties of blended oils soap.

Oil Type	Alkali Used	pH	Free Alkali Test	Hardness/ Texture	Foam Stability	Cleansing Power
Coconut oil + Castor oil	KOH	9.60	No	Soft	High	High
	NaOH	9.90	No	Hard	High	High
	CH_3ONa	9.60	No	Hard	High	High
Coconut oil + Olive oil	KOH	9.80	No	Soft	High	High
	NaOH	11.00	Yes	Hard	High	High
	CH_3ONa	9.83	Yes	Hard	High	High
Coconut oil + Palm oil	KOH	9.90	No	Soft	High	High
	NaOH	10.20	No	Hard	High	High
	CH_3ONa	10.00	No	Hard	High	High
Coconut oil + Sesame oil	KOH	10.00	No	Soft	High	High
	NaOH	9.80	No	Hard	High	High
	CH_3ONa	9.90	No	Hard	High	High
Coconut oil + Peanut oil	KOH	10.90	No	Soft	High	High
	NaOH	9.90	No	Hard	High	High
	CH_3ONa	10.00	No	Hard	High	High

7. Conclusion

This study demonstrated that blended oils combined with suitable alkalis, particularly CH_3ONa, produce high-quality soaps with optimized physicochemical properties. CH_3ONa consistently achieved the highest soap yields, while coconut-based blending oils increased foam stability, cleansing power, and balanced hardness. However, the pH ranges of our soaps were relatively high, which indicates the soaps are alkaline in nature. Thus, the soap could be suitable for laundry applications rather than bathing due to potential skin irritation. In conclusion, CH_3ONa with oil blends provides an efficient way for developing high-quality, customizable, and eco-friendly soaps in both industrial and artisanal applications.

Acknowledgments

The author, M. A. Hossain would like to thank the research funding from DRE/8/RUET/700(66)/PRO/2024-25/59(6). Gratitude is also addressed to the Head of the Research Laboratory, Department of Chemistry, Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh, for all support, and to the team members.

References

1. M. Lopes, S. M. Miranda, and I. Belo, Crit. Rev. Environ. Sci. Technol. **50**, 2583 (2020). https://doi.org/10.1080/10643389.2019.1704602
2. K. Ahmad and N. Mohammad, Recycling of Waste Cooking Oil to Produce Soaps and Detergents: Technical and Economic Feasibility Study (Palestine Polytechnic University, 2017). https://localhost:8080/xmlui/handle/123456789/6303
3. L. Zayed, N. Gablo, L. Kalcakova, S. Dordevic, I. Kushkevych, D. Dordevic, and B. Tremlova, Processes **12**, 1279 (2024). https://doi.org/10.3390/pr12061279

4. H. Soni, M. Kaur, and M. Verma, E3S Web Conf. **509**, ID 03014 (2024). https://doi.org/10.1051/e3sconf/202450903014
5. C. I. S. Rodrigues, J. J. Jackson, and M. D. Montross, Ind. Crops Prod. **92**, 165 (2016). https://doi.org/10.1016/j.indcrop.2016.07.030
6. E. A. Shalaby and N. S. El-Gendy, Int. J. Chem. Biochem. Sci. **1**, 30 (2012).
7. A. Juntuma, Electrochemical Synthesis of Methoxide for Transesterification of Palm Oil (2021). https://doi.org/10.58837/CHULA.THE.2021.32
8. D. G. Demisu, Int. J. Sustain. Energy **43**, ID 2305043 (2024). https://doi.org/10.1080/14786451.2024.2305043
9. J. Ashenhurst, Basic Hydrolysis of Esters-Saponification (2022). https://www.masterorganicchemistry.com/2022/10/27/saponification-of-esters/
10. N. P. Vidal, O. A. Adigun, T. H. Pham, A. Mumtaz, C. Manful et al., Molecules **23**, 2356 (2018). https://doi.org/10.3390/molecules23092356
11. D. Williams and G. S. Haines, Ind. Eng. Chem. Anal. Ed. **16**, 157 (1944). https://doi.org/10.1021/i560127a008
12. B. N. Alum, INOSR Appl. Sci. **12**, 51 (2024). https://doi.org/10.59298/INOSRAS/2024/12.2.515600
13. F. Gunstone, The Chemistry of Oils and Fats: Sources, Composition, Properties and Uses (John Wiley & Sons, 2009).
14. D. Mishra, PhD thesis, National Institute of Technology, Rourkela, India (2013).
15. F. Hashempour-Baltork, M. Torbati, S. Azadmard-Damirchi, and G. P. Savage, Trends Food Sci. Technol. **57**, 52 (2016). https://doi.org/10.1016/j.tifs.2016.09.007
16. N. K. Nasar, A. O. Alznati, and A. Arzoga, Sci. J. Appl. Sci. Sabratha Univ. 25 (2020). https://doi.org/10.47891/sabujas.v3i2.25-33
17. S. Arasaretnam and K. Venujah, Nat. Prod. Chem. Res. **7**, 2 (2019).
18. H. Zahran, Egypt. J. Chem. **67**, 9 (2024). https://doi.org/10.21608/ejchem.2023.195358.7627
19. A. A. Warra, L. G. Hassan, S. Y. Gunu, and S. A. Jega, Niger. J. Basic Appl. Sci. **18**, 315 (2010). https://doi.org/10.4314/njbas.v18i2.64350
20. M. A. S. Osman, Humanities & Nat. Sci. J. **5**, 193 (2024).
21. M. Baptista, I. Martins, T. Conceição, and P. Reis, Chem. Educ. Res. Pract. **20**, 760 (2019). https://doi.org/10.1039/C9RP00018F
22. D. Swern, Bailey's Industrial Oil and Fat Products (US Department of Energy, USA, 1982).
23. S. Rahayu, K. A. Pambudi, A. Afifah, S. R. Fitriani, S. Tasyari, M. Zaki, and R. Djamahar, J. Phys. Conf. Ser. **1869**, ID 012044 (2021). https://doi.org/10.1088/1742-6596/1869/1/012044
24. N. P. T. Nhan, T. T. Hien, T. H. N. Le, P. N. Q. Anh, L. T. Huy et al., Solid State Phenom. **279**, 235 (2018). https://doi.org/10.4028/www.scientific.net/SSP.279.235
25. V. G. Stănescu, V. Popescu, V. Vasilache, G. Popescu, C. M. Rîmbu, and A. Popescu, Appl. Sci. **15**, 3821 (2025). https://doi.org/10.3390/app15073821
26. E. G. Myers, Soap and Detergents, in Inedible Meat By-Products (Springer Netherlands, 1992) pp. 149. https://doi.org/10.1007/978-94-011-7933-1_7
27. B. Vincent, Adv. Colloid Interface Sci. **203**, 51 (2014). https://doi.org/10.1016/j.cis.2013.11.012
28. D. C. Poland and H. A. Scheraga, J. Phys. Chem. **69**, 2431 (1965). https://doi.org/10.1021/j100891a055
29. C. B. B. Farias, F. C. Almeida, I. A. Silva, T. C. Souza, H. M. Meira et al., Electron. J. Biotechnol. **51**, 28 (2021). https://doi.org/10.1016/j.ejbt.2021.02.002
30. R. D. C. F. Silva, D. G. Almeida, R. D. Rufino, J. M. Luna, V. A. Santos, and L. A. Sarubbo, Int. J. Mol. Sci. **15**, ID 12523 (2014). https://doi.org/10.3390/ijms150712523
31. F. T. Palmqvist and F. E. Sullivan, J. Am. Oil Chem. Soc. **36**, 173 (1959). https://doi.org/10.1007/BF02636971
32. J. Tarun, J. Susan, J. Suria, V. J. Susan, and S. Criton, Indian J. Dermatol. **59**, 442 (2014). https://doi.org/10.4103/0019-5154.139861

33. F. A. Atiku, I. M. Fakai, A. A. Wara, A. U. Birnin-Yauri, and M. A. Musa, Int. J. Adv. Res. Chem. Sci. **1**, 1 (2014).
34. S. T. Mabrouk, J. Chem. Educ. **82**, 1534 (2005). https://doi.org/10.1021/ed082p1534
35. S. K. A. Habib, M. S. Sorowar, J. Karmoker, M. K. Khatun, and S. M. Al-Reza, Int. J. Adv. Res. Chem. Sci. **3**, 9 (2016). https://doi.org/10.20431/2349-0403.0306002
36. L. Sukeksi and V. Diana, J. Phys. Conf. Ser. **1542**, ID 012046 (2020). https://doi.org/10.1088/1742-6596/1542/1/012046
37. L. Spitz and G. Mazzoni, J. Am. Oil Chem. Soc. **45**, 423 (1968). https://doi.org/10.1007/BF02655499
38. A. Hassan and I. G. Wawata, Equity J. Sci. Technol. **5**, 162 (2019).
39. M. R. Chirani, E. Kowsari, T. Teymourian, and S. Ramakrishna, Sci. Total Environ. **796**, ID 149013 (2021). https://doi.org/10.1016/j.scitotenv.2021.149013