

RESEARCH ARTICLE

VALORIZATION OF USED RICE BRAN OIL FOR THE PRODUCTION OF HARD AND LIQUID SOAP

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Received: 02 July 2026; Accepted: 26 September 2025; Published: 30 September 2026

ABSTRACT

Used rice bran oil (URBO) represents a potential non-food feedstock for value-added soap production. This study evaluated URBO for formulating hard and liquid soaps, along with activated-carbon pretreatment to improve the spent oil's visual quality. URBO with 26% total polar materials was filtered and treated with activated carbon at 10, 20, and 40 g/100 mL. The 20 g/100 mL treatment produced the greatest improvement in visual clarity and CIELAB colour and was selected for subsequent soap preparation. Hard soaps were prepared by the cold-process method, whereas liquid soaps were produced by the hot-process method. The formulations were evaluated for total fatty matter (TFM), total alkali, pH, moisture content, foam height, and preliminary sensory acceptability. For hard soap, TFM, total alkali, pH, moisture, and foam height ranged from 25.10 – 69.46%, 1.85 – 2.69%, 9.79 – 11.45, 8.90 – 14.86%, and 7.50 – 17.50 cm, respectively. T5 showed the highest TFM and foam height and the lowest total alkali, while its pH remained within the cited acceptable range. For liquid soap, TFM, total alkali, pH, and foam height ranged from 36.03 – 67.99%, 1.33 – 2.18%, 9.25 – 12.57, and 13.00 – 18.33 cm, respectively; T3 showed the highest TFM and foam height and the lowest alkali and pH. Sensory scores indicated generally favorable preliminary acceptability. These findings demonstrate the laboratory-scale feasibility of valorizing URBO in soap formulations, while further chemical characterization, control formulations, and broader consumer testing are required before conclusions on cleansing efficacy, skin safety, or commercial applicability. The work supports circular-economy approaches for redirecting degraded frying oil toward useful non-food products.

Keywords: Hard soap, Liquid soap, Saponification, Used rice bran oil, Waste cooking oil

INTRODUCTION

Edible oils are indispensable to human nutrition and food preparation worldwide, and deep-frying is one of the most prevalent and economically significant cooking techniques used in both domestic and industrial settings (Hammond, 2003; Dunford, 2019). During deep-frying, oils are subjected repeatedly to temperatures exceeding 180 °C in the presence of moisture and atmospheric oxygen, initiating a cascade of complex chemical reactions including oxidation, hydrolysis, polymerization, and thermally induced degradation (Nayak *et al.*, 2016; Farid, 2001; Latha and Nasirullah, 2014). These reactions progressively generate a range of harmful by-products such as polar compounds, free fatty

acids, trans-fatty acids, aldehydes, and polycyclic aromatic hydrocarbons (PAHs), which have been linked to oxidative stress, inflammation, and chronic non-communicable diseases in consumers (Cheong and Xu, 2019; Yongyod and Kerdsin, 2025; Kalogeropoulos *et al.*, 2007). As degradation advances, the oil undergoes visible physicochemical deterioration, manifesting as darkening in color, increased viscosity, excessive foaming, and a marked reduction in smoke point, all of which indicate a decline in both safety and functional quality (Kalogeropoulos *et al.*, 2007; Pardeshi, 2020). Therefore, used cooking oil (UCO) that has reached unacceptable deterioration should be removed from the food chain and directed to appropriate non-food uses. Globally, UCO is generated in enormous

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quantities, with annual production estimates ranging from 41 to 67 million metric tons, posing significant environmental and public health challenges when improperly disposed of through drainage systems, waterways, or landfills (Kim *et al.*, 2021). In Sri Lanka, as in many developing nations, UCO is often discarded without treatment or, more dangerously, recycled informally for repeated frying, increasing the accumulation of toxic degradation products (Panadare and Rathod, 2015). Nevertheless, UCO remains a substantial reservoir of residual fatty acids and glycerides with industrial value. According to the circular economy framework, valorizing UCO for the production of biodiesel, bio-lubricants, greases, and soaps represents both an environmentally responsible and economically viable strategy (Panadare and Rathod, 2015; Adane, 2020; Sari *et al.*, 2022). Soap manufacturing, in particular, offers a low-technology, cost-effective route for UCO valorization that is accessible to small and medium enterprises in developing economies (Ahadito and Afriani, 2024).

Rice bran oil (RBO) stands out among vegetable oils for its unique composition, comprising oleic, linoleic, and palmitic acids alongside a rich unsaponifiable fraction that includes γ -oryzanol, tocopherols, tocotrienols, phytosterols, and squalene (Cheong and Xu, 2019; Dunford, 2019; Ali and Devarajan, 2017). These bioactive compounds confer exceptional oxidative stability and a high smoke point of approximately 232 °C, making RBO particularly well-suited for high-temperature frying applications (Zhao *et al.*, 2021; Dunford, 2019). However, when subjected to repeated or prolonged heating cycles, RBO undergoes progressive physicochemical deterioration characterized by increasing free fatty acid content, accumulation of total polar compounds, reduction of tocopherol levels, hydrolysis of triglycerides, and partial degradation of unsaturated fatty acid chains (Latha and Nasirullah, 2014; Zou *et al.*, 2022). Regulatory agencies such as the Food Safety and Standards Authority of India (FSSAI) stipulate that frying oils exceeding 25% total polar compounds (TPC) must be withdrawn from use, underscoring the need for responsible end

-of-life management of spent RBO (Latha and Nasirullah, 2014). Although oryzanol shows greater thermal resilience than other antioxidants, the cumulative burden of degradation by-products renders URBO unfit for further culinary use and requires diversion to non-food industrial channels.

Despite its degradation for culinary purposes, URBO retains a chemically rich composition of residual triglycerides, free fatty acids, and unsaponifiable constituents that render it a viable feedstock for soap manufacturing. In the saponification reaction, triglycerides and free fatty acids react with strong alkaline solutions of sodium hydroxide (NaOH) or potassium hydroxide (KOH), converting the oil into fatty acid salts (soap) and glycerol as a co-product (Panadare and Rathod, 2015). The relatively high saponification value of RBO, attributed to its well-balanced fatty acid profile, supports the production of soaps with desirable emollient and conditioning properties (Dunford, 2019; Cheong and Xu, 2019). Furthermore, residual γ -oryzanol in URBO may add skin-conditioning functionality, offering a potential value-added attribute not commonly associated with other waste cooking oils (Ali and Devarajan, 2017). Blending URBO with supplementary oils such as coconut oil, which provides lauric acid for lathering and hardness, castor oil for foam stabilization and conditioning, and olive oil for moisturizing properties, can further optimize the functional performance of the resultant soap products (Spitz, 2016). Sodium laureth sulfate (SLES) is a supplementary anionic surfactant that enhances lather formation and supports the cleansing performance of soap formulations, as it is widely used in cleansing products for its effective surfactant and foaming properties (Dick *et al.*, 2024). Its concentration was kept constant within each formulation series to minimize its influence on comparisons among treatments.

Previous studies have demonstrated the feasibility of converting used UCO into soap, including laundry and toilet soaps prepared from mixed waste vegetable oils, palm-derived waste oils, and blends containing coconut oil (Adane, 2020; Maotsela *et al.*, 2019;

Ahadito and Afriani, 2024). However, the use of URBO as the primary lipid feedstock for soap production remains less documented. This is particularly relevant because rice bran oil has a characteristic fatty-acid profile dominated by oleic, linoleic, and palmitic acids and contains a substantial unsaponifiable fraction comprising γ -oryzanol, tocopherols, tocotrienols, phytosterols, and squalene (Lerma-García *et al.*, 2009; Punia *et al.*, 2021). Pretreatment of degraded frying oils is also important because repeated frying generates pigments, oxidation products, polar compounds, and other impurities that may affect the quality of the oil used for subsequent processing. Adsorbent treatments, including activated carbon, have been reported to improve the color and selected physicochemical characteristics of used frying oils by adsorbing degradation products and impurities (Bhattacharya *et al.*, 2008; Turan, 2021). Activated carbon has also been shown to improve the color and reduce free fatty acids and other deterioration indices of used cooking oils under appropriate treatment conditions.

Accordingly, this study investigated URBO as the principal oil phase for developing both hard and liquid soap formulations. The study also evaluated activated-carbon treatment at different concentrations, selecting the treatment based on improvements in visual clarity and CIELAB color characteristics before soap manufacture. URBO was subsequently blended with coconut, castor, and/or olive oils at different proportions, and the resulting formulations were evaluated for TFM, total alkali content, pH, moisture content, foamability, and preliminary sensory acceptability. Therefore, the study extends existing waste-oil valorization research by providing formulation- and quality-related information specifically for URBO-based hard and liquid soaps.

MATERIALS AND METHODS

The research was conducted at the Department of Biosystems Technology, Faculty of Technology, Southeastern University of Sri Lanka. All experimental work was carried out in a well-ventilated laboratory at 25 ± 2 °C and 50 – 60% relative humidity.

MATERIALS

The research used the following raw materials and chemicals:

Oils: Rice bran oil (collected from a commercial meat-frying processing facility in Homagama, Sri Lanka), coconut oil, castor oil, and olive oil (all food-grade, stored in airtight containers at 25 ± 2 °C away from direct sunlight).

Alkalis: Sodium hydroxide (NaOH, analytical grade) and Potassium hydroxide (KOH, analytical grade), stored in desiccators to prevent moisture absorption.

Other chemicals: Nitric acid (HNO₃, analytical grade), Chloroform (analytical grade), Phenolphthalein (indicator), Glycerine (food-grade), EDTA (disodium salt, analytical grade), Sodium silicate, Calcium carbonate, synthetic dyes, Fragrance oils, and Sodium Lauryl Ether Sulfate (SLES).

Other materials: Laboratory glassware, hot-plate stirrer, soap moulds, pH meter (calibrated before use), hot water bath, analytical balance, oven, and stick blender. Caustic chemicals (NaOH, KOH, HNO₃, chloroform) were handled using personal protective equipment (PPE) such as gloves, lab coats, and safety goggles. Work was carried out in a fume hood to prevent inhalation hazards, with appropriate first aid measures and neutralizing agents (dilute acetic acid) available in case of accidental exposure.

Collection and pretreatment of URBO

URBO was collected from a commercial meat-frying processing facility in Homagama, Sri Lanka, after repeated frying and when the oil was withdrawn from further frying. As the oil was obtained from routine industrial processing, the exact number of frying cycles was not available. The collected URBO was tested for TPM, and it recorded a value of 26%. Frying oil with a TPM value exceedingly approximately 24 – 25% is generally considered unsuitable for further frying (Debnath *et al.*, 2012; Gertz, 2000). Therefore, the collected oil was considered sufficiently deteriorated for removal from food use and was subsequently utilized for non-food soap production. The present study did not determine acid value/free fatty acid content, peroxide value, iodine value, or saponification value; therefore, TPM

was used as the principal indicator of frying-oil deterioration. A 25 L sample of URBO with a TPM value of 26% was collected for the study. The oil was initially filtered twice through cotton cloth to remove large suspended particles, then filtered through Whatman No. 1 filter paper to remove finer particulate matter. Activated carbon treatment was employed as an adsorptive pretreatment to reduce visible pigments, odour-producing compounds, and other adsorbable impurities in the filtered URBO. Different activated-carbon levels were evaluated to identify a treatment capable of improving the appearance and clarity of the oil while minimizing excessive charcoal carry-over. Activated carbon was prepared by sieving coconut-shell charcoal to 1.0 – 5.0 mm (sieves 4 – 16), soaking it in 25% CaCl₂ solution for 24 h, then thoroughly rinsing and drying it at 100 °C for 1 h (Cobb *et al.*, 2012).

For the adsorption treatment, activated carbon was added to 100 mL of filtered URBO at three levels: 10 g/100 mL (T1), 20 g/100 mL (T2), and 40 g/100 mL (T3). The mixtures were maintained at room temperature for 24 h and subsequently filtered through Whatman No. 1 filter paper. The color of the treated oil was measured using a colourimeter (NH310, Shenzhen 3nh Technology Co., Ltd., China),

and the CIELAB color parameters L*, a*, and b* were recorded. The optimum activated-carbon treatment was selected based on improvements in visual clarity and instrumental CIELAB color measurements. The selected treated oil was stored in an airtight amber-colored glass bottle at 25 ± 2 °C to minimize oxidation prior to soap preparation. All hard- and liquid-soap formulations were prepared using URBO treated with activated carbon at 20 g/100 mL.

Soap preparation

The hard soaps in this study were prepared using the cold process method, which is widely preferred for producing high-quality soaps as it preserves the natural glycerin formed during saponification and allows better control over the final texture and hardness of the soap (Spitz, 2016; Retnowati *et al.*, 2013). Ingredients, including URBO, coconut oil, castor oil, olive oil, glycerin, and other additives, were measured precisely (Table 1) to ensure complete saponification and prevent excess lye or oil, which can affect soap safety and quality.

The dye solution was prepared by gradually adding NaOH to cold distilled water while continuously stirring until fully dissolved, then cooled to 20 – 25 °C. Oils and additives

Table 1: Formulations and treatment composition of hard soap prepared using used rice bran oil and other vegetable oils

T	Composition (%)	NaOH (%)	Water (%)	Glycerin (%)	Na ₂ SiO ₃ (%)	CaCO ₃ (%)	Dye (%)	Fragrance (%)	EDTA (%)	SLES (%)
T1	URBO	45.12								
	CO	15.00	10.58	23.08	1.19	2.50	0.96	0.04	0.38	0.96
T2	URBO	42.08								
	CAO	12.04	10.58	23.08	1.19	2.50	0.96	0.04	0.38	0.96
	OO	6.00								
T3	URBO	42.08								
	CO	12.04	10.58	23.08	1.19	2.50	0.96	0.04	0.38	0.96
	CAO	6.00								
T4	URBO	42.08								
	CAO	12.04	10.58	23.08	1.19	2.50	0.96	0.04	0.38	0.96
	CO	6.00								
T5	URBO	38.80								
	CO	14.82	10.58	23.08	1.19	2.50	0.96	0.04	0.38	0.96
	CAO	6.50								

Where; T: Treatment, URBO : Used Rice bran oil, CO: Coconut oil, CAO: Castor oil, OO: Olive oil

were blended using a stick blender (Moulinex, DD45A1, China) at 300–400 rpm, after which the lye solution was slowly incorporated with constant stirring for 2–4 minutes until the mixture reached trace, characterized by the soap thickening and leaving a visible trail on the surface. The mixture was then poured into rectangular moulds (10 × 5 × 5 cm) and left to solidify for 24–48 h. After demolding, the soap bars were cured in a well-ventilated room at 25 ± 2 °C for 3 weeks to achieve appropriate hardness and moisture reduction. Soap bars were wrapped in oiled paper and stored in a cool, dry, and dark place to prevent moisture absorption and maintain quality (Spitz, 2016). Each treatment was prepared in three replicates, arranged in a Completely Randomized Design (CRD).

Liquid soap preparation

The liquid soaps were prepared using the hot-process method (Bakhri *et al.*, 2023), with all ingredients thoroughly mixed; each treatment was prepared in triplicate under a Completely

Randomized Design (CRD) (Table 2). Oils and additives, including used rice bran oil, coconut oil, castor oil, and other components, were blended at 300–400 rpm using a magnetic stirrer (C-MAG HS 7, IKA-Werke GmbH and Co. KG, Staufen, Germany). The KOH solution was gradually added while continuously stirring for 2–4 min until trace was achieved, indicated by slight thickening and the mixture leaving a visible trail on the surface. The soap mixture was heated at 60–80 °C for 2–3 h with constant stirring to ensure complete saponification. Then mixture was diluted with hot water at a 1:1.5 ratio, then glycerin, fragrance, and colourants were added and thoroughly mixed to ensure homogeneity (Silsia *et al.*, 2017; Kurniawati and Paramita, 2022; Bakhri *et al.*, 2023). The liquid soap was formulated to achieve a pH of 9–10 and a viscosity suitable for consumer use. Finished liquid soaps were stored in PET bottles at 25 ± 2 °C, away from direct sunlight, to maintain stability and prevent microbial growth (Spitz, 2016).

Table 2: Formulations and treatment composition of liquid soap prepared using used rice bran oil and other vegetable oils

T	Composition (%)	KOH (%)	Water (%)	Glycerin (%)	Na ₂ SiO ₃ (%)	CaCO ₃ (%)	Dye (%)	Fragrance (%)	SLES (%)
T1	URBO 40.00								
	CO 26.50	6.00	22.50	0.91	1.76	0.74	0.44	0.74	0.74
T2	RBO 50.00								
	CO 11.50	6.00	22.50	0.91	1.76	0.74	0.44	0.74	0.74
	OO 5.00								
T3	RBO 50.00								
	CO 11.50	6.00	22.50	0.91	1.76	0.74	0.44	0.74	0.74
	CAO 5.00								

Where; T : Treatment, URBO : Used rice bran oil, CO: Coconut oil, CAO : Castor oil and OO : Olive oil.

Analytical determinations

Determination of total fatty matter (TFM) content of hard soap and liquid soap

The 5 g of soap sample was dissolved in 100 mL of hot water. About 40 mL of 0.5 N HNO₃ was added to make it acidic. The mixture was heated until the fatty acids floated in a layer above the solution. It was cooled in ice water to solidify the fatty acids. The fatty acids were separated, and the aqueous solution was treated with 50 mL of chloroform to remove the remaining fatty acids. The separated fatty substances were mixed, the solvent was evaporated, and the yield was noted. The total fat percentage was calculated using the

following formula,

$$\begin{aligned} \text{Weight of soap sample} &= 5 \text{ g} \\ \% \text{ of fatty matter} &= \frac{(y - x) \times 100}{\text{Weight of soap sample}} \end{aligned} \quad \text{Eq.1}$$

Where; X : Weight of the China dish, Y : Weight of China dish + Soap after drying

Determination of total alkali content of hard soap and liquid soap

To determine the total alkali content, 5 g of soap sample was dissolved in 100 mL of hot water. Add about 40 mL of 0.5 N HNO₃ to

make it acidic. The mixture was heated until the fatty acids floated as a layer above the solution. It was cooled in ice water to solidify the fatty acids. The fatty acids were separated, and the aqueous solution was treated with 50 mL of chloroform to remove the remaining fatty acids. The aqueous solution

was measured, and 10 mL of it was titrated against 0.5 N NaOH using methyl orange as an indicator. The total alkali content was calculated from the titer value using the following method (Arasaretnam and Venujah, 2019).

$$\begin{aligned}
 &\text{Total volume of the aqueous solution (V)} &&= \text{mL} \\
 &10 \text{ mL of aqueous solution requires } t \text{ (titer value of NaOH) mL of NaOH} \\
 &V \text{ mL of aqueous solution requires } V \times t / 10 &&= (A) \text{ mL.} \\
 &\text{Amount of NaOH required by acid in aqueous solution} &&= A \text{ mL} \\
 &B \text{ mL (Volume of HNO}_3 \text{ required)} &&= A \times \frac{\text{Normality of NaOH}}{\text{Normality of HNO}_3} \\
 &C \text{ (volume of HNO}_3 \text{ required for neutralizing NaOH)} &&= 40 - B \\
 &E \text{ (amount of NaOH in 1000 cc of soap solution)} &&= \frac{(C \times 40 \times \text{Normality of HNO}_3 \text{ g})}{1000} \\
 &F \text{ (250 cc of soap solution contains)} &&= (E \times 250) / 1000 \text{ g} \\
 &2\text{NaOH} \text{-----} \text{Na}_2\text{O} + \text{H}_2\text{O} \\
 &80 \text{ grams of NaOH, } 62 \text{ g of Na}_2\text{O} \\
 &F \text{ g of NaOH requires (Y)} &&= (62 \times F) / (80) \text{ g of Na}_2\text{O} \\
 &W \text{ (weight of soap taken)} &&= 5 \text{ g} \\
 &\% \text{ of alkalinity} &&= \frac{Y}{W} \times 100
 \end{aligned}$$

Eq. 2

Determination of pH of hard soap and liquid soap

For both hard and liquid soaps, weigh approximately 10 g of each sample and dilute with distilled water to a final volume of 100 mL. The pH meter was calibrated with standard buffer solutions of pH 7.0 and 10.0 before measuring the pH of the prepared soap solutions (Adane, 2020).

Determination of foamability of hard soap and liquid soap

Place approximately 2 g of each soap in a 500 mL graduated cylinder containing 100 mL of distilled water. Shake the mixture vigorously to produce foam. After shaking for about 2 minutes, the cylinder was left to stand for about 10 minutes. The foam height in the solution was measured and recorded.

Determination of moisture content of the hard soap

Moisture content of the hard-soap samples was determined by drying approximately 5 g

of each sample in an oven at 103 ± 2 °C until a constant mass was obtained. Moisture content was calculated from the mass loss after drying (Adane, 2020).

Sensory evaluation

Based on the physicochemical evaluation, the best-performing hard- and liquid-soap formulations were selected for subsequent sensory evaluation using a 9-point hedonic scale,

$$\text{Moisture Content} = \frac{C_S - C_L}{C_S - C_W} \times 100$$

Eq. 3

Where; C_W : Weight of crucible, C_S : Weight of crucible + sample and C_L : Weight of crucible + sample after drying

where 1 = “dislike extremely” and 9 = “like extremely” (Stone and Sidel, 2004). Thirty semi-trained panelists, comprising male and female participants aged 20-60 years, participated in the evaluation. For hard soap, panelists evaluated color, aroma, smoothness,

foaming quality, washing quality, and overall acceptability. For liquid soap, panelists assessed color, aroma, viscosity, smoothness, foaming quality, washing quality, and overall acceptability. Panelists evaluated each formulation independently and rinsed their hands with water between samples to minimize carry-over effects. Panelists recorded sensory scores individually for subsequent statistical analysis. The sensory evaluation was conducted in accordance with the ethical requirements of the Ethics Review Committee (ERC), Faculty of Technology, South Eastern University of Sri Lanka, University Park, Oluvil, Sri Lanka. The committee granted ethical approval (Approval No. ERC/FT/2024/027, dated 29 January 2024). All participants were informed about the purpose and procedures of the study before participation, and written informed consent was obtained before the sensory evaluation. Participation was voluntary, and participants were informed that they could withdraw from the study at any time without penalty. Participant information was kept confidential and used only for research purposes.

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA), with formulation as the independent factor. When the ANOVA indicated a significant treatment effect ($p < 0.05$), mean separation was performed using Tukey's honestly significant difference (HSD) test. Results are presented as mean $\pm$ standard deviation of

three independent replicates ($n = 3$). Assumptions of normality and homogeneity of variance were assessed prior to ANOVA. Sensory data were analyzed using the Friedman test, followed by the Wilcoxon signed-rank test with Bonferroni adjustment for multiple pairwise comparisons. Sensory results are presented as mean $\pm$ standard deviation (SD), and statistical significance was considered at an adjusted $p < 0.05$.

RESULTS AND DISCUSSION

Effect of activated-carbon treatment on the color and visual quality of used rice bran oil

The untreated used rice bran oil exhibited a dark brown color with visible suspended impurities, reflecting the deterioration associated with repeated frying (Figure 1). Activated-carbon treatment produced clear treatment-dependent changes in oil appearance and CIELAB color parameters (Table 3). Treatment 1 (10 g/100 mL) produced a moderate improvement in lightness, with the L^* value increasing from 38.50 ± 1.20 in the untreated oil to 46.20 ± 1.10 , accompanied by reductions in a^* and b^* values. Treatment 2 (20 g/100 mL) showed the greatest improvement in visual clarity and lightness, with the highest L^* value (58.40 ± 1.30) and markedly lower a^* (5.90 ± 0.40) and b^* (32.50 ± 1.00) values compared with the untreated oil (Table 3).

These changes corresponded with the clearer, lighter yellow-brown appearance observed visually (Figure 1). In contrast, Treatment 3

Table 3: Effect of activated carbon treatment on the visual appearance and CIELAB color parameters of used rice bran oil

T	Activated charcoal	Visual observation	L^*	a^*	b^*
Untreated URBO	0 g/100 mL	Dark brown and turbid	38.50 ± 1.20^c	14.80 ± 0.60^a	42.00 ± 1.30^a
T1	10 g/100 mL	Slightly lighter; impurities remained	46.20 ± 1.10^b	10.70 ± 0.50^b	38.60 ± 1.20^b
T2	20 g/100 mL	Clearer, light yellow-brown	58.40 ± 1.30^a	5.90 ± 0.40^d	32.50 ± 1.00^c
T3	40 g/100 mL	Darker due to excess charcoal	31.80 ± 1.40^d	8.60 ± 0.50^c	28.40 ± 0.90^d

T: Treatment, Values are expressed as mean $\pm$ standard deviation (SD). Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$). Untreated URBO: 0 g/100 mL, T1: 10 g/100 mL, T2: 20 g/100 mL, T3: 40 g/100 mL activated carbon

(40 g/100 mL) showed a decrease in L^* to 31.80 ± 1.40 , indicating increased darkening despite reductions in a^* and b^* . This may have resulted from excessive activated-carbon loading or retention of fine carbon particles during filtration. Based on both the visual appearance (Figure 1) and CIELAB colour

measurements (Table 3). Treatment 2 was selected as the most suitable activated-carbon treatment for subsequent hard- and liquid-soap preparation.

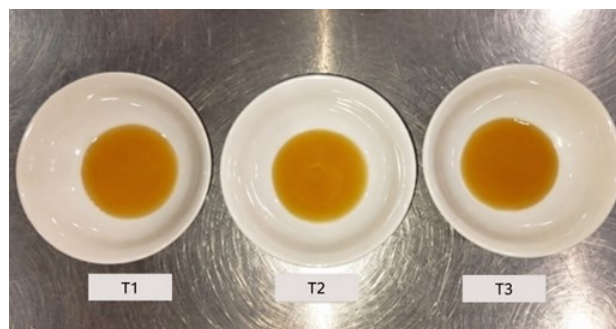


Figure 1: Visual appearance of used rice bran oil after activated-carbon treatment: T1:10 g/100 mL, T2: 20 g/100 mL; and T3: 40 g/100 mL activated carbon

Physicochemical properties of hard soap formulations

The physicochemical results (Table 4) indicated that used cooking oils (UCOs) can be converted into soap through direct saponification (Shimizu, 1988). In this

study, the formulated hard soaps were evaluated for key physicochemical properties, including total fatty matter, total alkali content, moisture content, pH, and foamability, and the relevant results were

Table 4: Physicochemical properties of hard-soap formulations prepared using used rice bran oil

Properties	Values				
	T1	T2	T3	T4	T5
TFMC (%)	51.42 ± 1.72^b	25.10 ± 2.96^c	30.10 ± 1.78^c	46.98 ± 4.73^b	69.46 ± 0.62^a
TAC (%)	2.44 ± 0.28^a	2.53 ± 0.049^a	2.69 ± 0.43^a	2.58 ± 0.00^a	1.85 ± 0.32^b
MC (%)	14.86 ± 0.14^a	11.67 ± 1.65^b	9.96 ± 0.1^c	8.90 ± 0.49^c	12.49 ± 0.21^b
pH	10.67 ± 0.15^b	11.08 ± 0.45^a	11.45 ± 0.23^a	11.17 ± 0.06^a	9.79 ± 0.29^c
FH (cm)	15.17 ± 0.29^b	7.50 ± 0.50^c	15.17 ± 0.29^b	12.50 ± 0.50^b	17.50 ± 0.50^a

TFMC : Total Fatty Matter Content, TAC : Total Alkali Content, MC : Moisture Content, FH : Foam Height

Values are expressed as mean $\pm$ standard deviation (SD) of three independent replicates ($n = 3$). Different superscript letters within the same row indicate significant differences among formulations ($p < 0.05$; Tukey's HSD test).

T1: 45.12% URBO + 15.00% CO, T2: 42.08% URBO + 12.04% CAO + 6.00% OO, T3: 42.08% URBO + 12.04% CO + 6.00% CAO, T4: 42.08% URBO + 12.04% CAO + 6.00% CO, T5: 38.80% URBO + 14.82% CO + 6.50% CAO.

compared with the specifications prescribed in SLS 554:2016 for laundry soap.

Total fatty matter (TFM) of formulated hard soaps

The TFM values of the prepared hard soap samples ranged from $25.10 \pm 2.96\%$ to $69.46 \pm 0.62\%$ (Table 4). T5 recorded the highest TFM value (69.46%) and exceeded the cited

SLS value of 59%, whereas T1–T4 remained below this value. Therefore, interpret compliance with the TFM criterion individually for each formulation.

Higher TFM values are strongly associated with improved cleansing efficiency, enhanced lathering ability, and reduced skin irritation because TFM reflects the proportion of pure

soap in the final product (Nova *et al.*, 2025). Soaps with higher TFM generally contain fewer impurities and exhibit better performance characteristics, including milder action on the skin and more efficient removal of oils and dirt (Uduma *et al.*, 2025). In contrast, formulations with lower TFM values, such as Treatments 1–3, may indicate incomplete saponification, excess moisture, or higher proportions of non-soap components such as fillers or unreacted oils. Such factors can reduce the overall effectiveness and quality of the soap (Silva *et al.*, 2024).

Total alkali content of formulated hard soaps

The total alkali content of the prepared soap samples ranged from $1.85 \pm 0.32\%$ to $2.69 \pm 0.43\%$ (Table 4). Only formulation T5 (1.85%) falls below the commonly referenced threshold of $\sim 2\%$ total alkali, often considered acceptable to minimize skin and fabric irritation, according to product-quality assessments of soaps (Gautam and Acharya, 2025). The higher values observed in T1 through T4 suggest a mild surplus of unreacted alkali (or free/combined alkali), likely due to incomplete saponification or insufficient neutralization of the lye with fatty acids. Excess alkali in soap formulations can contribute to skin dryness, irritation, and disruption of the skin's natural lipid barrier during washing because alkali can react with skin surface lipids and strip them away (Gunathilake *et al.*, 2007; Khosrowpour *et al.*, 2019). By contrast, soaps with lower total alkali while still maintaining adequate TFM are less aggressive.

Moisture content of formulated hard soaps

Moisture content is a key factor used to assess a product's shelf life. Excess water reacting with saponified fat would produce glycerol and free fatty acids in soap with high MC values. According to Spitz (2016), the permissible moisture content of hard soap is between 10% and 15%. The MC of the soap samples ranged from $8.90 \pm 0.49\%$ to $14.86 \pm 0.14\%$ (Table 4). According to laundry soap quality specifications, the moisture and volatile matter content should generally not exceed 30% by mass. In this study, most treatments met this requirement, while T4 showed a compar-

atively lower moisture content of 8.90%. This lower moisture content may contribute to increased hardness and better storage stability; however, excessively low moisture may also affect product handling, brittleness and dissolution behaviour during washing (East African Community, 2011; ASTM International, 2023).

pH of formulated hard soaps

The pH values ranged from 9.79 to 11.45 (Table 4). Based on the cited acceptable upper limit of pH 10.0, T1–T4 exceeded this limit, whereas T5 (9.79 ± 0.29) was within the stated range. Among the formulations exceeding the limit, T2–T4 had pH values above 11, while T1 exceeded the limit by a smaller margin at pH 10.67. Elevated soap pH may reflect residual alkali and can increase skin pH and delay its recovery after washing (Gunathilake *et al.*, 2007). In contrast, T5 exhibited the lowest pH and remained within the stated acceptable range. Highly alkaline soap formulations may therefore have greater potential to disturb normal skin-surface pH and barrier function (Gunathilake *et al.*, 2007).

Foamability of formulated hard soaps

Foamability varied significantly among the soap formulations, with foam heights ranging from 7.50 cm to 17.50 cm (Table 4). Foam height is an important physicochemical quality parameter for soap because it reflects the ability of surface-active compounds to reduce surface tension and entrap air, thereby producing lather during washing (Nova *et al.*, 2025). Among the formulations, T5 showed the highest foam height (17.50 cm), indicating better lathering capacity and suggesting improved surfactant performance. This is desirable for laundry soap, as good foam formation is commonly associated with effective wetting, soil removal, and consumer acceptability. However, foam height alone should not be considered the only indicator of cleaning efficiency (Khan *et al.*, 2011). In contrast, T2 recorded the lowest foamability (7.50 cm), which may be attributed to reduced surface-active matter, incomplete saponification, or impurities/oily residues that can interfere with foam formation and stability (Khan *et al.*, 2011).

The higher foam height in T5 suggests that this formulation has better lathering characteristics and may be more suitable for laundry soap applications than the other treatments. Because SLES was present in all formulations, the observed foam height reflects the combined contribution of the saponified oils

and SLES. It cannot be attributed solely to the URBO-derived soap.

Physicochemical properties of liquid-soap formulations

The physicochemical results (Table 5) indicated the quality characteristics of the formulated

Table 5. Physicochemical properties of liquid-soap formulations prepared using used rice bran oil

Properties	Value		
	T1	T2	T3
TFMC (%)	57.55 ± 1.22 ^a	36.03 ± 2.09 ^b	67.99 ± 1.19 ^c
TAC (%)	2.06 ± 0.24 ^a	2.18 ± 0.08 ^a	1.33 ± 0.07 ^b
pH	10.33 ± 0.14 ^b	12.57 ± 0.03 ^a	9.25 ± 0.011 ^c
FH (cm)	16.00 ± 0.50 ^b	13.00 ± 0.50 ^c	18.33 ± 0.76 ^a

TFMC : Total Fatty Matter Content, TAC : Total Alkali Content, MC : Moisture Content, FH : Foam Height

Values are expressed as mean ± standard deviation (SD) of three independent replicates (n = 3). Different superscript letters within the same row indicate significant differences among formulations ($p < 0.05$; Tukey's HSD test).

T1: 40.00% URBO + 26.50% CO, T2: 50.00% URBO + 11.50% CO + 5.00% OO, T3: 50.00% URBO + 11.50% CO + 5.00% CAO

liquid soaps prepared using used cooking oil (UCO). The liquid soap samples were evaluated for key physicochemical parameters, including pH, total alkali content, total fatty matter, and foamability, and the values were compared with relevant liquid soap quality requirements.

Total Fatty Matter (TFM) of formulated liquid soaps

Total fatty matter (TFM) varied clearly among the liquid soap formulations. Treatment 3 recorded the highest TFM value ($67.99 \pm 1.19\%$), followed by Treatment 1 ($57.55 \pm 1.22\%$), while Treatment 2 showed the lowest value ($36.03 \pm 2.09\%$). TFM is an important quality parameter in soap evaluation because it represents the proportion of fatty substances, including saponified and saponified fatty acids, present in the final product (Andualem *et al.*, 2026). Therefore, the higher TFM value observed in Treatment 3 suggests more efficient incorporation and conversion of oils into soap, resulting in a richer formulation with better potential cleansing and mildness properties.

Soap quality is strongly influenced by physicochemical parameters such as TFM, pH, foaming ability, moisture content, and total alkali content; therefore, TFM should be dis-

cussed together with these parameters rather than as a single quality indicator (Nova *et al.*, 2025). The comparatively high TFM of Treatment 3 may reflect a more balanced oil-to-alkali ratio and improved saponification efficiency, which could have increased the amount of fatty acid salts responsible for cleansing and lathering. Higher fatty matter in soap is generally associated with better product richness, smoother feel, improved mildness, and reduced harshness, especially when excess free alkali is low (Andualem *et al.*, 2026). Treatment 1 also showed a moderate TFM value, indicating acceptable formulation quality, although it was lower than Treatment 3. In contrast, the markedly low TFM value of Treatment 2 may be due to dilution effects from higher water content, insufficient oil incorporation, incomplete saponification, or a higher proportion of non-soap additives. Since liquid soaps naturally contain more water than bar soaps, lower TFM values may occur; however, very low TFM can reduce active soap content and may negatively affect cleansing performance, viscosity, foam stability, and consumer acceptability (Nova *et al.*, 2025).

Total alkali content of formulated liquid soaps

The total alkali content differed significantly among the liquid soap formulations. Treat-

ment 3 had the lowest total alkali content ($1.33 \pm 0.07\%$) compared with Treatment 1 ($2.06 \pm 0.24\%$) and Treatment 2 ($2.18 \pm 0.08\%$), while Treatments 1 and 2 were statistically similar. The lower residual alkali content in Treatment 3 suggests a more complete saponification reaction, with most of the alkali used to form fatty acid salts. This indicates a better balance between the oil phase and potassium hydroxide during formulation. In contrast, the relatively higher alkali contents observed in Treatments 1 and 2 may be due to excess alkali addition, incomplete saponification, or poor oil incorporation during processing.

Similar soap quality studies have used total alkali content, free caustic alkali, pH and total fatty matter as key physicochemical indicators for assessing soap quality and safety. From a product-quality perspective, lower residual alkali is desirable because excess alkali can increase soap harshness and may affect user comfort, especially with repeated use. Studies on rinse-off products in Sri Lanka reported that alkaline soaps increase skin pH and slow the recovery of normal skin acidity. In contrast, another dermatological study showed that alkaline soaps can increase trans epidermal water loss, skin pH and erythema. Therefore, the lower alkali level in Treatment 3 indicates better mildness potential and improved suitability as a liquid soap formulation compared with Treatments 1 and 2.

pH of formulated liquid soaps

Treatment 2 had the highest pH (12.57 ± 0.03), followed by Treatment 1 (10.33 ± 0.14), while Treatment 3 had the lowest pH (9.25 ± 0.01). Since saponifying oils or fats produce soap with alkali, finished soap products are expected to have a slightly to moderately alkaline pH. Excessively high pH usually indicates residual or unreacted alkaline materials, particularly when it is also associated with higher total alkali content. Therefore, the very high pH observed in Treatment 2 is consistent with its higher alkali content and may suggest incomplete saponification or excess KOH addition during formulation. Total alka-

li is recognized as an important soap quality parameter, and ISO 685:2020 includes total alkali and total fatty matter determination for soaps, including liquid soaps. From a safety and consumer-acceptability perspective, controlling pH matters because highly alkaline soaps can disrupt the skin's natural acidic condition. Healthy human skin normally has an acidic surface pH of about 4.5–5.5, which supports the skin barrier and normal microbiome.

Foamability of formulated liquid soaps

Foamability differed among the liquid soap formulations, with Treatment 3 showing the highest foamability (18.33 ± 0.76 cm), followed by Treatment 01 (16.00 ± 0.50 cm), while Treatment 2 recorded the lowest value (13.00 ± 0.50 cm). Foam height is an important physicochemical parameter in soap quality evaluation because it reflects surfactant molecules' ability to reduce surface tension and entrap air during agitation, thereby producing lather. Previous studies have used foam height as a key quality indicator for commercial soaps and liquid hand washes, with reported foam heights ranging from 6.83 to 25.16 cm.

The superior foamability of Treatment 3 may be attributed to its higher total fatty matter, which indicates a greater proportion of fatty acid salts formed during saponification. These fatty acid salts act as surface-active compounds and support lather formation and foam stability. The lower residual alkali and lower pH of Treatment 3 may also have contributed to better foaming performance, as a well-balanced formulation allows surfactants to function more effectively. Surfactant type, concentration, and the presence of oily matter or impurities influence lathering performance and can either enhance or suppress foam development.

Treatment 1 also showed satisfactory foamability, suggesting acceptable surfactant formation and lathering potential. In contrast, the lower foamability of Treatment 2 may be associated with its reduced total fatty matter and excessive alkalinity. Low fatty matter can re-

duce the amount of active soap available for foam generation, while higher residual alkali or unreacted materials may disturb foam formation and reduce product acceptability. Although foam height alone does not fully determine cleansing efficiency, good foamability matters because consumers usually associate rich, stable lather with effective cleaning performance and better product quality. Therefore, Treatment 3 is the most desirable formulation in terms of foamability and consumer appeal. Because SLES was present in all formulations, the observed foam height reflects the combined contribution of the saponified oils and SLES. It cannot be attributed solely to the URBO-derived soap.

Sensory evaluation of the selected hard-soap formulation

The sensory scores of the hard soap ranged from 6.57 to 7.87 on the 9-point hedonic scale (Figure 2). Washing quality received the highest mean score (7.87), followed by foaming quality (7.73), overall acceptability (7.63), aroma (7.60), and smoothness (7.60), whereas color received the lowest score (6.57). The results indicate generally favorable sensory responses across the evaluated attributes, although color showed comparatively lower acceptability. The error bars represent standard deviations, indicating the variability in panelists' responses. Different letters above the bars indicate statistically significant differences among sensory attributes ($p < 0.05$).

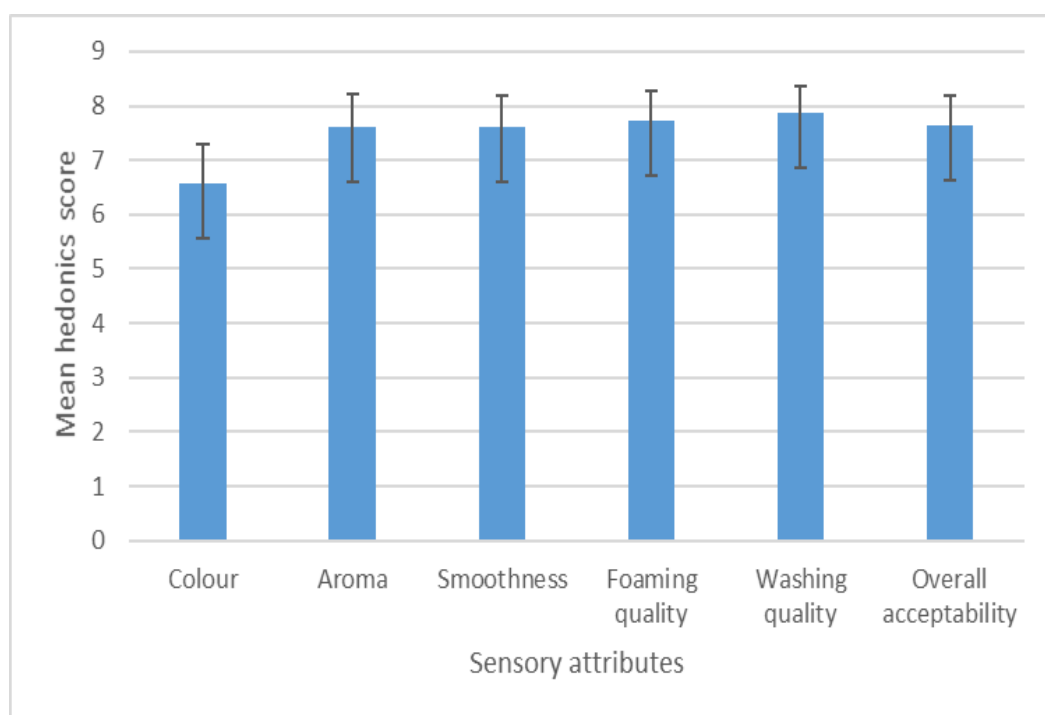


Figure 2: Sensory acceptability of the selected hard-soap formulation (T5: 38.80% URBO, 14.82% CO, and 6.50% CAO) evaluated by 30 semi-trained panelists using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Values are presented as mean $\pm$ SD for color, aroma, smoothness, foaming quality, washing quality, and overall acceptability ($p < 0.05$)

Sensory evaluation of the selected liquid-soap formulation

The sensory scores of the selected liquid-soap formulation were generally high across all evaluated attributes (Figure 3). The mean scores were 7.55 for color, 7.50 for aroma, 7.30 for viscosity, 7.56 for smoothness, 7.53 for foaming quality, 7.60 for washing quality,

and 7.63 for overall acceptability on the 9-point hedonic scale. Overall acceptability received the highest mean score, followed by washing quality and smoothness, whereas viscosity recorded the lowest mean score. These results indicate generally favorable sensory responses toward the selected liquid-soap formulation.

CONCLUSION

The present study demonstrates the laboratory-scale feasibility of utilizing used rice bran oil (URBO) as a major lipid feedstock for hard-

and liquid-soap formulations. Activated-carbon treatment at 20 g/100 mL produced the greatest improvement in visual clarity and CIELAB color characteristics and was there-

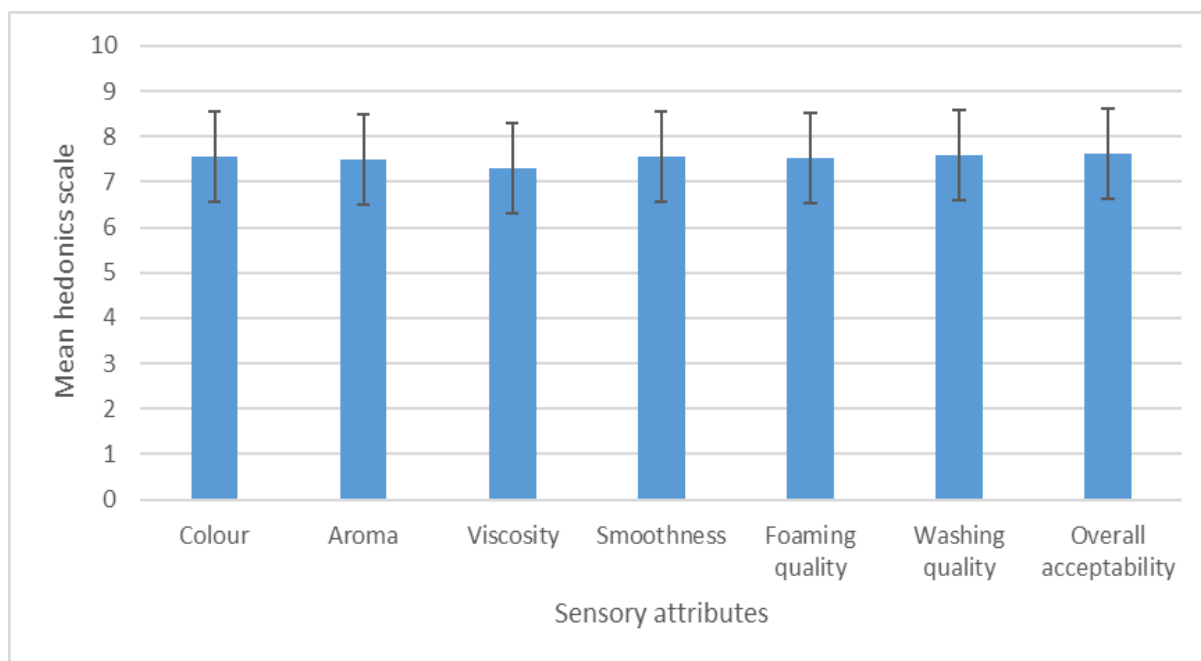


Figure 3: Sensory acceptability of the selected liquid-soap formulation (T3: 50.00% URBO, 11.50% CO, and 5.00% CAO) evaluated by 30 semi-trained panelists using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Values are presented as mean $\pm$ SD for color, aroma, viscosity, smoothness, foaming quality, washing quality, and overall acceptability ($p < 0.05$)

fore selected as the pretreatment condition. However, interpret this improvement primarily in terms of color and clarity, as oxidative and hydrolytic quality parameters were not measured before and after adsorption. Among the hard-soap formulations, T5 showed the highest TFM (69.46%) and foam height (17.50 cm), the lowest total alkali content (1.85%), and a pH of 9.79. In contrast, T1–T4 exceeded the cited upper pH limit, indicating that not all formulations met the referenced pH criterion. For liquid soap, T3 showed the highest TFM (67.99%) and foam height (18.33 cm), together with the lowest total alkali content (1.33%) and pH (9.25). Sensory evaluation indicated generally favorable preliminary responses for both soap types. Overall, the findings support valorizing URBO as a potential non-food application within a circular-economy framework. However, this study did not evaluate direct cleansing effi-

ciency, skin safety, shelf life, market acceptance, or commercial-scale feasibility. A limitation of the present study is that FTIR and GC-based fatty-acid profiling were not performed; therefore, molecular-level changes in the oil and soap formulations could not be confirmed. Future studies should include FTIR and GC-based fatty-acid characterization, virgin-oil and SLES-free control formulations, and larger consumer studies before drawing broader conclusions about product performance or commercialization.

AUTHOR CONTRIBUTION

SMB conducted the experiments, collected and analyzed the data, and prepared the initial draft of the manuscript. HAPWH conceptualized and designed the study, supervised the research, interpreted the results, and reviewed and revised the manuscript. JASJ provided technical and industrial guidance, supported

the experimental work, and reviewed the manuscript. All authors read and approved the final manuscript.

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